SYLLABUS ON RADIOGRAPHY

RADIATION PROTECTION

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DEAR READER:

This document is the sixth revision of the Radiography Syllabus. Your review and comments of this revision would be sincerely appreciated. Please mail your comments to:

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The Radiologic Health Branch, within the California Department of Health Services, is responsible for administering the rules and regulations developed pursuant to the Radiologic Technology Act. The Act was passed by the California Legislature and signed by then Governor Ronald Reagan in 1969[1/]. The purpose of the Act is the following:

- To protect the people of California from excessive and/or improper exposure to ionizing radiation.

- To establish standards of good practice for X-ray personnel - radiologic technologists, X-ray technicians, and doctors - X-ray operators and supervisors.

The Radiologic Technology Certification Committee

The Radiologic Technology Certification Committee (RTCC) was established through provisions of the original legislation. The main function of the RTCC is to provide advisory services to the Director of the Department of Health Services and to give expert assistance to the Radiologic Health Branch in developing rules, regulations, and training standards regarding safe use of X-rays on human beings.

Current members of the State of California's Radiologic Technology Certification Committee are:

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1/ Laws Relating to Radiologic Technology, Division 20, Chapter 7.4, sections 106965 to 107110, inclusive, and sections 114859 to 114895, inclusive, (old sections 25660 to 25699.3, inclusive) California Health and Safety Code.

FORMER MEMBERS OF THE RADIOLOGIC TECHNOLOGY CERTIFICATION COMMITTEE

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Represented radiologic physicists:

Caridad Borras, D.Sc., San Francisco
Robert L. McDermott, M.S., Pasadena
John W. Schaeflein, M.S., D.A.B.R., Hacienda Heights

STATUTES REGARDING X-RADIATION

A. Laws Relating to Radiologic Technology.

Laws that govern the use or supervision of use of X-radiation on human beings are found in sections 106965 to 107110, inclusive, and sections 114705 to 114895, inclusive, (old sections 25660 to 25699.3, inclusive) of the California Health and Safety Code.

B. Radiation Control Laws.

Applicable provisions for X-ray equipment safety are:

Sections 114960 - 115000, inclusive, (old sections 25800 - 25811, inclusive), sections 115060 - 115110, inclusive, (old sections 25815 - 25826, inclusive), sections 115130 - 115170, inclusive, (old sections 25835 - 25856, inclusive) of the California Health and Safety Code.

C. Regulations Relating to Radiologic Technology.

Regulations relating to radiologic technology are found in sections 30400 to 30468, inclusive, of the California Code of Regulations (CCR), title 17.

D. California Radiation Control Regulations, including 10 CFR 20 (the Nuclear Regulatory Commission Regulations), incorporated in section 30253, California Code of Regulations (CCR), title 17.

Regulations relating to radiation control are found in sections 30100 - 30146, inclusive, and sections 30250 - 30313, inclusive, of the California Code of Regulations (CCR), title 17.

In this syllabus applicable provisions of the radiation laws and regulations will be either reworded or quoted verbatim. There is no need for you - the radiologic technologist - to purchase a complete set of statutes because your X-ray supervisor/doctor must make the laws and regulations readily available to you. If your X-ray supervisor/doctor does not have these statutes, please advise him/her to obtain a complete set of statutes by contacting BARCLAY LAW PUBLISHERS either by telephone (415) 244-6611or 1-800-888-3600, or by writing to:

BARCLAY LAW PUBLISHERS
P.O. Box 3066
South San Francisco, CA 94083-3066

Barclay's Code Number for title 17 is 17 01 542; for complete package including (1) 10 CFR 20, (2) CCR, title 17, and (3) amendments Barclay's Code Number is 17 01 552. Price: Inquire.

Please be reminded that regulations do not repeat provisions that are clearly stated in the law. Thus, neither law alone nor regulations alone will provide adequate answers to many questions that you may have regarding the "provisions of the radiation laws and regulations."

NOTE: The Health and Safety Code has been recodified pursuant to the SB 1360 (Chapter 415, Statues of 1995). The legislation reorganized, renumbered, and made technical changes to the public health portion of the Health and Safety Code (H&SC).

ACKNOWLEDGEMENTS

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Pamela J. Henderson, M.S. and Melissa Martin, M.S., D.A.B.R. contributed new material and edited the 4th draft (2/25/87) of the Syllabus on Radiography Radiation Protection.

Val Zemitis, Radiation Protection Specialist (RHB) compiled the original material, established the format for presentation, and prepared the current revision of the syllabus.

The review of the **original** syllabus by many individuals is herewith acknowledged. Especially helpful have been suggestions of John W. Schaeflein, Radiologic Physicist, D.A.B.R.; Roland A. Finston, Ph.D., Director, Health Physics, Stanford University; Troy L. Brannon, M.S., Nuclear Physicist; and Hyman Bernstein, Ph.D., Professor, U.C.L.A.

Special appreciation goes to James A. Seibert, Ph.D., Associate Professor, U.C.D., for his valuable suggestions in the preparation of the current publication and to the following members of the Southern California Chapter of the American Association of Physicists in Medicine: Marilyn Wexler, M.S., Melissa Martin, M.S., and Martin W. Herman, Ph.D.

Within the Radiologic Health Branch Don Honey, Supervising Health Physicist, David Wheeler, Senior Health Physicist, was of great assistance in finalizing the current revision. Mr. Edward W. Gloor, Mr. Eustace Douglas, Jr., Shirley Geddes, Paul Graveline, and Jeff Clifford contributed valuable suggestions and reviewed the current publication. Hank Kocol, CHCM, Associate Health Physicist, Phillip Scott, HP, and Roger Lupo, HP, made numerous and valuable editorial and technical suggestions.

Radiologic Health Branch wishes to express its appreciation to various publishers and companies who have provided RHB material or permitted RHB to copy from their publications (in alphabetical order):

- Delmar Publishers Inc., Two Computer Drive West, Box 15-015, Albany, New York 12212. Publication: Richard R. Carlton and Arlene McKenna Adler, **Principles of Radiographic Imaging**, 2nd edition, 1996.

- Mosby Year Book, Inc., 11830 Westline Industrial Drive, St. Louis, Missouri 63146. Publications:

  (1) Stewart C. Bushong, Sc.D., **Radiologic Science for Technologists**, 5th edition, 1993; and **Workbook and Laboratory Manual**, 5th edition, 1993.

  (2) Mary Alice Statkiewicz-Sherer, et al, **Radiation Protection in Medical Radiography**, 2nd edition, 1993.

- W.B. Saunders Company, The Curtis Center, Independence Square West, Philadelphia, PA 19106. Publications:

  (1) Steven B. Dowd, **Practical Radiation Protection and Applied Radiobiology**, 1st edition, 1994.

  (2) Michael A. Thompson, et al, **Principles of Imaging Science and Protection**, 1st edition, 1994.

- Charles C. Thomas, Publisher, 2600 South First Street, Springfield, IL 62717. Publications:

  (1) Joseph Selman, M.D., **The Fundamentals of X-Ray and Radium Physics**, 7th edition, 1985.

  (2) Joseph Selman, M.D., **Elements of Radiobiology**, 1st edition, 1988.

- Williams & Wilkins, 428 East Preston Street, Baltimore, MD 21202. Publications:

  (1) Bushberg, Jerrold T., Ph.D., James A. Seibert, Ph.D, et al, **The Essential Physics of Medical Imaging**, 1st edition, 1994.

  (2) Thomas S. Curry, III, M.D. et al, **Christensen's Physics of Diagnostic Radiology**, 4th edition, 1990.

Because of space limitations, much of the available material had to be condensed, abridged, or paraphrased. The Radiologic Health Branch assumes the sole responsibility for the content of this syllabus.

PREFACE

This syllabus is not a textbook but rather a guide to good practice in diagnostic radiation protection. It provides information on how to produce diagnostic quality radiographs with the least radiation dose to the patient, the operator and others.

The syllabus also provides information for preparing for the State radiation protection examination:

- Licentiates of the Healing Arts are responsible for knowing all of the provisions of the syllabus.
- Diagnostic radiologic technologists should know all of the provisions noted in the syllabus.
- Therapeutic radiologic technologists should refer to Chapters VII to X, Appendices 1 to 5, and applicable entries in the Glossary.

Elimination of unnecessary exposure to ionizing radiation requires the holder of a Radiology Certificate or Radiography Supervisor and Operator permit to use qualified judgement in deciding whether X-raying a patient is essential, to know the yield of X-ray examinations, and not to take more views than appropriate.

Supervisors must exercise proper supervision over X-ray personnel and ensure that they follow standing orders and perform their assigned tasks conscientiously and correctly. Supervisors are also responsible for ensuring that appropriate quality assurance (QA) and quality control (QC) tests are performed on the X-ray and ancillary equipment and for ascertaining that the X-ray equipment is in safe operating condition at all times. They are also responsible for action of radiologic technologists and X-ray technicians to produce radiographs which provide maximum diagnostic information with minimum radiation exposure to the patient, X-ray personnel and others. X-ray personnel must be especially careful when X-raying children or persons of reproductive age. In these instances X-ray personnel must pay special attention to avoid gonad exposure.

It is unfortunate that terminology regarding radiologic technology and radiation protection is not uniform. For example: terms such as "collimate" and "restrict" are used interchangeably. In the syllabus, such terms often are presented in this form: "collimate/restrict."

The mention of commercial products, their sources, or their use is not to be construed as either actual or implied endorsement of such products by the California State Department of Health Services.

NOTE: This syllabus contains over 48,000 words, 7,000 sentences, and 4,500 paragraphs. The average word length is 5 letters and the average sentence length is 6 words. The estimated readability is 10-12 grade level. Estimated time required to prepare for the examination is 4 - 6 hours.

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APPENDICES

INTRODUCTION

The first case of human injury from X-ray exposure was reported in the scientific literature in 1895, just a few months following publication of Roentgen's original paper in 1895 announcing the discovery of X-rays. As early as 1902, the first case of X-ray induced cancer was reported.

Evidence that harmful effects can result from a large exposure to ionizing radiation existed in the 1920s and 30s, based upon the experience of the early radiologists and persons working in the radium industry. The potential long-term biological significance of smaller, chronic exposures of ionizing radiation, however, was not appreciated until much later, and most of our current knowledge of the biological effects of radiation has been accumulated since World War II.

Over 90 percent of the average population's exposure from manmade ionizing radiation sources comes from medical uses of radiation. **The largest contribution to this total radiation dose to the population from manmade radiation sources results from medical radiographic examinations. There is little doubt that the obvious and immediate benefits of medical X-ray examinations justify incurring biological and genetic risks. However, estimates indicate that at least 30 percent, and possibly more, of the exposure from diagnostic X-ray examinations could be eliminated without decreasing patient benefit.** Indeed, with the use of modern X-ray and ancillary equipment, accessories, and correct radiation safety precautions, the amount of radiation exposure needed to obtain a diagnostic quality radiograph is negligible compared to the immediate benefit obtained from the X-ray procedure. Nevertheless, each radiography supervisor[1/] should endeavor to eliminate the unproductive exposure of patients to X-radiation by following information offered in this syllabus.

Basically, a radiologic service involves three distinct phases:

1. Determining whether the patient should have an X-ray examination – a licentiate (physician) responsibility, not discussed in this syllabus.

2. Performing the examination – radiologic technology personnel responsibility for taking radiographs and performing related duties, and Radiology certificate or Radiography Supervisor and Operator permit holder responsibility for supervising radiologic technology personnel.

3. Interpreting the radiological findings – a qualified licentiate responsibility, not discussed in this syllabus.

[1/] Sections 30460 to 30468, inclusive.

NOTE: Unless otherwise specifically indicated, the above and subsequent section citations refer to California Code of Regulations (CCR), title 17. Sections 30100 to 30397, inclusive, are California Radiation Control Regulations and sections 30400 to 30468, inclusive, are California Regulations Relating to Radiologic Technology.

CHAPTER I

RADIOGRAPHY UTILIZATION

Studies of X-ray utilization (that is, the use of X-rays in diagnostic procedures) provide data on the volume and distribution of diagnostic radiographic examinations. These studies also indicate why examinations are performed.

Studies of population exposure to X-rays have indicated that the most procreative age group (that is, 15 to 29 years of age) received an annual average of 600 medical radiographic examinations per 1,000 population. Those in age group 30 to 44 received approximately 800 radiographic examinations per 1,000 population per year. On the average, the annual number of radiographic examinations per person X-rayed was 1.6. The number of films taken per examination was 2.2.

Most (64 percent) of X-ray examinations were performed in hospitals. Private physician groups accounted for 7 percent, private offices for 19 percent, and health agencies and others for 10 percent.

The distribution of radiographic examinations by body area was as follows: thoracic areas accounted for approximately 50 percent of all examinations; abdominal areas, 25 percent; extremities, 17 percent; head and neck and other examinations, 8 percent.

It has been estimated that radiological examinations are increasing at a rate greater than 7 percent per year and can be expected to continue increasing at this rate.

Studies have indicated that about 43 percent of the U. S. population is X-rayed for medical and 22 percent for dental purposes every year. Exposure to such a large part of the population, even at the low levels of diagnostic radiation used, is cause for concern. Nevertheless, **the available data confirms that the best course of action is to obtain necessary diagnostic information from radiographic examinations, accepting a small statistical increase of risk. At the same time, however, it is vital to minimize radiation exposure to patients and X-ray personnel by adhering to the principles of radiation protection as explained in Chapter II and by exercising proper and adequate supervision over radiologic technology personnel as elaborated in Chapter XI.**

CHAPTER II

FACTORS INFLUENCING PATIENT RADIATION DOSE

After deciding that a radiographic examination is necessary, the condition of X-ray equipment, accessories, and the manner in which that examination is conducted will influence the radiation dose to the patient as well as determine the quality of the image produced. Knowledge and understanding of the basic factors influencing patient radiation dose are necessary in order to produce the best quality radiographs with the minimum amount of radiation dose to patients.

The factors influencing patient radiation dose are:

A. X-ray tube and X-ray equipment.

1. X-ray tube.
2. Filtration.
3. Collimation or X-ray beam restriction.
4. Tabletop and vertical cassette holder.

B. Accessories.

1. Gonad shields and gonad shielding.
2. Grids.
3. Cassettes.
   a. Cassette fronts.
   b. Intensifying screens.

C. Radiographic or X-ray film and film processing.

1. Radiographic/X-ray film.
2. Optimum processing techniques.

D. Primary factors and technique chart.

1. Kilovoltage (kVp).
2. Milliampere-seconds (mAs).
3. Target-to-film distance (TFD).
4. Technique chart.

E. Patient and patient positioning.

1. Patient.
2. Absorption and scatter.
3. X-ray beam – part being X-rayed – film alignment.

F. Ancillary factors.

1. X-ray generator design.

Many of the factors mentioned on page 3 (such as the X-ray tube, filtration or tabletop) cannot be influenced by X-ray personnel during the day-to-day use of X-ray equipment. Other factors such as grids, cassettes, intensifying screens, radiographic film and technique chart can be changed or modified periodically. **Factors that can be directly influenced by X-ray personnel are:**

- **Proper collimation**
- **Proper use of gonad shielding**
- **Correct use of primary factors (kilovoltage, milliamperage, time, and distance)**
- **Correct patient positioning**
- **Proper use of grids, cassettes, and caliper**
- **Proper film handling and film processing**

Each factor that influences patient radiation dose will be explained briefly here and elaborated in detail on pages 7 through 29.

A. X-RAY TUBE AND X-RAY EQUIPMENT.

1. **X-ray tube.** X-rays are produced by energy conversion when a fast-moving stream of electrons is suddenly decelerated in the "target" (anode) of an X-ray tube (see pages 7 - 9).

2. **Filtration.** Filters, usually made of aluminum, are located in the useful (primary) X-ray beam to preferentially absorb or eliminate the less penetrating X-rays before they reach a patient. Filtration is necessary to protect the patient's skin from receiving unnecessary radiation (see pages 9 - 11).

3. **Collimation (X-ray beam restriction/area exposed/field size).** Collimation of the useful or primary X-ray beam to the area of clinical interest is required by law. Collimation is one of the most important actions X-ray personnel can take in order to avoid unnecessary radiation dose to the patient (see pages 11, 12).

4. **Tabletop and vertical cassette holder.** Tabletops and vertical cassette holders must be made of material such as aluminum, Bakelite, or carbon fiber that do not appreciably attenuate the passage of X-rays (see page 12).

B. ACCESSORIES.

1. **Gonad shielding.** Suitable protective devices must be used to shield or protect gonads in potentially procreative patients when gonads cannot be excluded from the useful X-ray beam and the shielding of gonads does not interfere with the diagnosis (see pages 12 - 15).

2. **Grids.** The function of a radiographic grid is to reduce the scattered radiation produced in the patient (part being X-rayed) before it reaches the X-ray film (see pages 15 - 18).

3. **Cassettes:** A cassette is a thin, light-tight X-ray film holder containing intensifying screens mounted within front and spring-loaded back structures (covers) which are hinged together (see page 18).

   a. **Cassette fronts.** The front surface of the cassette must be made of material that has a low atomic number such as carbon fiber, cardboard, Bakelite, or aluminum (see page 18).

   b. **Intensifying screens.** Today most X-ray films are exposed in a cassette with intensifying screens. The intensifying screens convert the energy of the X-ray beam into visible light that then exposes the X-ray film (see pages 18, 19).

C. **RADIOGRAPHIC/X-RAY FILM AND FILM PROCESSING.**

1. **Radiographic film/X-ray film.** Nowadays most X-ray examinations are performed on so-called screen films in cassettes using intensifying screens. X-rays that strike the intensifying screens are converted into light (fluorescence) and this fluorescence on the screen exposes the film (see pages 19, 20).

2. **Film processing techniques.** Even the best X-ray equipment and careful selection of primary factors (kilovoltage, milliamperage, time, and distance) will not produce satisfactory radiographs unless the darkroom, the processor, and the processing techniques are of optimum quality. Film processing must be done according to the film manufacturer's recommendations (see pages 20, 21).

D. **PRIMARY FACTORS AND TECHNIQUE CHART.**

1. **Kilovoltage (kVp).** The kilovoltage (kVp) used determines the maximum photon energy (quality) of the X-ray beam produced (see pages 21, 22).

2. **Milliampere-seconds (mAs).** X-ray tube current is measured in milliamperes (mA) and the exposure time in seconds or fraction of a second (s = time). The quantity/amount of X-rays produced is directly proportional to both the milliamperes (mA) and time (s) selected (see pages 22, 23).

3. **Target-to-film distance (TFD)/Source-to-image distance (SID).** X-rays are produced when a fast-moving stream of electrons hits a "target," generally made of tungsten. The target, then, is the origin of the X-ray beam. It has been established that a 40-inch target-to-film distance is optimal for most radiographic examinations (see pages 23, 24).

4. **Technique chart.** The selection of primary factors (kVp, mA, time, and distance) should be done by consulting a technique chart. Use of caliper to determine body part thickness, where the central ray (CR) will enter the body part, is necessary for assisting X-ray personnel in selecting appropriate values of primary factors (see pages 25, 26). Incorrect selection of primary factors accounts for most of the repeated radiographs (retakes/repeats).

E. **PATIENT AND PATIENT POSITIONING.**

1. **Patient.** The body part being X-rayed determines the degree of attenuation of an X-ray beam as it passes through the patient. Radiographic image contrast is largely dependent upon differences in tissue density (see pages 26, 27).

2. **Absorption and scatter.** When an X-ray photon interacts with matter, it is either absorbed and removed from the beam or scattered. In radiography, the patient (body part being X-rayed) is the main source of scattered radiation. Factors affecting scattered radiation are:

   - o Kilovoltage (kVp) used
   - o Field size (area exposed)
   - o Part thickness (volume exposed)
   - o Tissue density (Z number)

It is essential to reduce the production of scattered radiation by reducing/collimating/restricting the useful or primary X-ray beam to the area of clinical interest only (see pages 27, 28).

3. **X-Ray Beam -- Part Being X-rayed -- Film Alignment.** Alignment of the X-ray beam with the part being X-rayed and the film, is essential. To assist X-ray personnel in this task most radiographic tubes have a light beam that shows the area being exposed to X-rays. The light beam must be properly aligned with the part being radiographed and the X-ray film (see page 28). Incorrect positioning, regrettably, accounts for many repeated radiographs.

F. ANCILLARY FACTORS.

1. **X-Ray generator design.** Generators available for X-ray systems include single-phase, three-phase, medium/high frequency, and constant potential designs. There are certain technical advantages of three-phase generators and medium/high frequency generators over one- or two-phase generators such as:

   - o High mA available for short exposure times
   - o High effective kilovoltage
   - o Near constant potential

(See page 29)

FACTORS INFLUENCING PATIENT RADIATION DOSE

It is the responsibility of each radiography supervisor (licentiate) to ensure that the X-ray equipment and accessories he/she possesses are optimum for the X-ray procedures to be performed. Also, the radiography supervisor is responsible for ensuring that all X-ray personnel under his/her jurisdiction know the factors that influence patient radiation dose, as explained on the following pages.

A. X-RAY TUBE AND X-RAY EQUIPMENT.

1. X-ray tube.

X-rays (also referred to as "X-ray photons" or "photons") are primarily produced by energy conversion when a fast moving stream of electrons is suddenly decelerated in the "target" of an X-ray tube (see Figure 1). This process is called **Brems radiation (brehmsstrahlung or "breaking" radiation)**. Energy conversion takes place when the kinetic energy of the electrons is transformed into electromagnetic radiation. The energies of the resultant X-ray photons range from very low up to a maximum equal to the energy of the accelerated electron. **The resultant X-ray beam consists of a spectrum of energies, referred to as a heterogeneous, polyenergetic, or polychromatic beam.**

There is a second process that involves the incoming electron "knocking out" or "displacing" an orbital electron from a target atom. When the atom replaces the electron, an X-ray is produced. These X-rays are known as **"characteristic"** X-rays as their energies are a function of the target material. This process produces very small percentage of the X-rays in the beam.

The X-ray tube is made of Pyrex glass which encloses a vacuum and contains two major parts -- a negative electrode or filament called the **cathode** and a positive electrode containing the target called the **anode** (see Figure 1). Electrons are released from the heated tungsten filament **(thermionic emission)** and accelerated by a high potential difference (in diagnostic radiography between 50,000 and 120,000 volts or 50 and 120 kilovolts) across the tube to hit the tungsten target where X-rays are produced. **Only about 1 percent of the energy deposited in the target by these electrons is converted to X-rays while the other 99 percent is converted to heat that must be dissipated by the anode.**

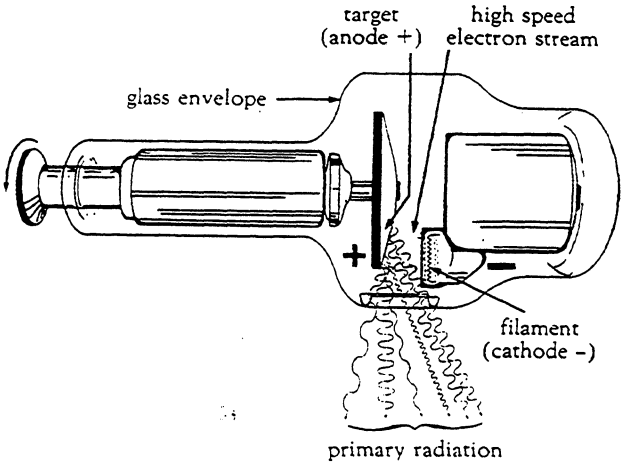

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Figure 1. Principal parts of a modern rotating-anode X-ray tube.

The X-ray tube is mounted inside a lead-lined protective tube housing (see Figure 2).

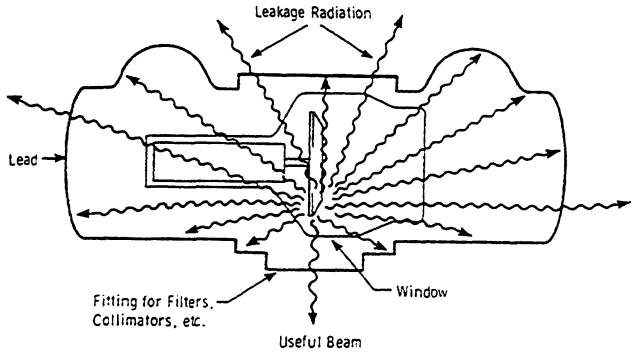

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Figure 2. Protective housing reduces the intensity of leakage radiation to safe levels.

When an electron stream hits the "target," X-rays are produced in all directions. However, only X-rays that are emitted through the "window" (see Figure 2) constitute the so-called "useful beam" (sometimes also called "primary X-ray beam"). Other X-rays that penetrate through the protective X-ray tube housing are called "leakage radiation" and serve no useful purpose.

The number of X-rays produced depends primarily on the number of electrons that flow from the filament (cathode) to the target (anode) of the X-ray tube. The X-ray tube current, measured in milliamperes (mA), is adjusted by controlling the filament current and refers to the **quantity** of electrons flowing per second and is related to the number of X-rays produced per second. Fixed stations, usually of 100, 200, and 300 milliamperes (mA), are available on modern X-ray equipment. A tube current of 200 mA produces twice as many electrons as a current of 100 mA, and 200 mA produces twice as many X-rays per second as does 100 mA.

In many modern X-ray tubes, the anode rotates to spread the heat load over a wider surface area (see Figure 1, page 7). The anode angle is usually 12 to 20 degrees. The actual size of the tungsten target is considerably larger than the area bombarded by the electron stream (the focal spot) (see Figure 3). **The size of the focal spot influences resolution of the image.**

The line-focus principle allows high anode heating with small effective focal spots. As the target angle decreases, so does the effective focal spot.

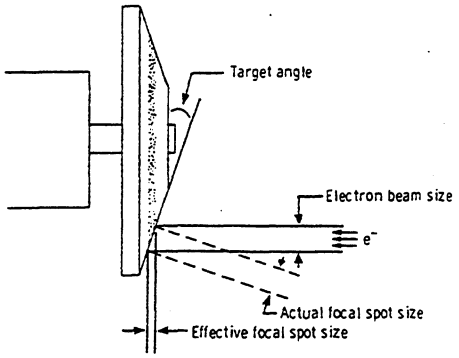

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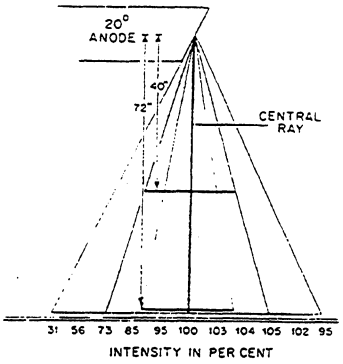
Figure 3. Line focus principle.

The so-called "heel effect" is the result of the line-focus principle that distributes radiation intensity more on the cathode side than on the anode side (see Figure 4). At a 40-inch target-to-film distance, the anode end on a 14 x 17 inch film will receive a relative exposure of 73 percent, and the cathode end will receive a relative exposure of 105 percent. Thus, there is about a 30 percent difference in the intensity of exposure between the two ends of the film (see Figure 4). If the target-to-film distance is 72 inches, then the intensity distribution is approximately 87 to 104 percent. For smaller size films the heel effect plays a lesser role. If one is X-raying a patient the anode end of the X-ray tube should be opposite the thinner end of the part being X-rayed to decrease the change in film density across the sloping surface.

The heel effect results in reduced X-ray intensity on the anode side of the useful X-ray beam because of absorption of the X-rays in the "heel" by the target.



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Projections that may use the anode heel effect to advantage:

Projection	Body part to be placed toward	
	Cathode end of tube	Anode end of tube
Femur (AP and lateral)	hip	knee
Lower leg (AP and lateral)	knee	ankle
Humerus (AP and lateral)	shoulder	elbow
Forearm (AP and lateral)	elbow	wrist
Thoracic spine (AP)	abdomen	neck
Thoracic spine (lateral)	neck	abdomen
Lumbar spine (AP and lateral)	pelvis	abdomen

2. Filtration.

A filter is defined as a material placed in the useful (primary) X-ray beam to preferentially absorb the less penetrating radiations [Section 30306 (f)]. It is usually made of aluminum or equivalent material and placed in the useful or primary beam (see Figure 2, page 8). **The main purpose of the filter is to reduce the number/amount of low-energy (long wavelength) X-rays from reaching the patient.** Low energy X-rays cannot completely penetrate through a body to reach the X-ray film and, therefore, contribute nothing to the diagnostic image. However, appropriate filtration also accomplishes the following:

- Reduce scattered radiation
- Improve the quality of the radiograph
- The X-ray beam becomes less polychromatic (more monochromatic)

Even at high kilovoltage settings (50 to 120 kVp) common in modern X-ray techniques, the X-ray beam contains many X-rays of lower penetrating ability (energy) that have no value in most X-ray examinations (see Figure 5) and add a great deal of unnecessary radiation dose to the patient.

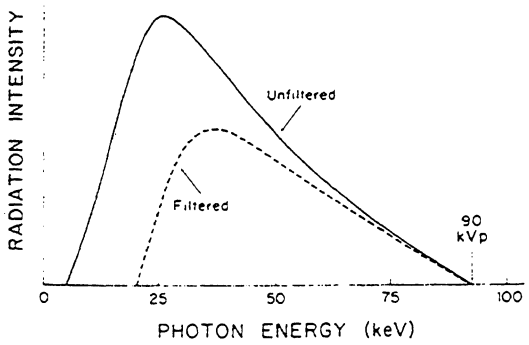

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Figure 5. Energy and intensity of unfiltered and filtered polychromatic radiation.

At 110 kVp and with a 1.0 mm aluminum filter, a typical radiation dose at 40 inches (101.6 cm) target-to-panel distance is 26.0 millirads/mAs. At 110 kVp and with a 2.5 mm aluminum filter, the radiation dose at 40 inches (101.6 cm) target-to-panel distance is reduced to 11.0 millirads/mAs. Therefore, by using added filtration, the radiation dose reduction is approximately 42 percent, mostly achieved by preferential removal of the low energy X-rays from the X-ray beam (spectrum).

Half-Value Layer (HVL).

The QUALITY or penetrating ability of the X-ray beam is characterized by the half-value layer (HVL). The HVL is defined as the thickness of absorbing material necessary to reduce the X-ray intensity to half its original value. For example: If the radiation dose rate from an X-ray tube is 10 millirads per minute, and a filter of 4 millimeters of aluminum is added, and is found to reduce the radiation dose rate to 5 millirads per minute, then the half-value layer (HVL) of the X-ray beam would be 4 millimeters of aluminum.

Figure 6 illustrates the procedure for determining the half-value layer (HVL).

The concept of a half-value layer (HVL) is also used in shielding, where lead is the material of choice to attenuate X-rays. For example: In order to reduce a 100 millirads per minute radiation dose rate to 25 millirads per minute of radiation dose rate, two half-value layers would be required (see Appendix 2, pages 71, 72).

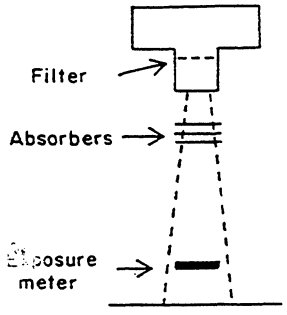

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Figure 6. The procedure for determining the half-value layer (HVL) of an X-ray beam.

Filtration Regulatory Requirements.

For radiographic machines manufactured after August 1, 1974, the half-value layer (HVL) of the useful beam for a given X-ray tube potential shall not be less than the appropriate value noted below:

kVp operating range	Measured operating potential (in kVp)	Minimum HVL millimeters of aluminum
Below 50 kVp	30	0.3
	40	0.4
	49	0.5
50 to 70 kVp	50	1.2
	60	1.3
	70	1.5
Above 70 kVp	71	2.1
	80	2.3
	90	2.5
	100	2.7
	110	3.0
	120	3.2
	130	3.5
	140	3.8
	150	4.1

The **total filtration** of an X-ray beam includes filtration from the inherent filter and any added filter(s).

Inherent filter: Inherent filtration includes the X-ray tube and its housing such as the glass envelope (window) through which the X-ray beam passes. The inherent filtration is approximately 0.5 mm lead equivalent.

Added filter: Added filtration includes sheets of metal (usually aluminum) placed in the direct path of the X-ray beam.

Scoliosis filters. Those X-ray facilities that provide scoliosis studies of children should utilize lightweight leaded-plastic compensating filters that will provide not only greater diagnostic detail but also will considerably reduce radiation dose. **Scoliosis examinations should be taken with breast shields to reduce the radiation dose to the breasts or with the patient in a posterior-anterior position.**

3. Collimation.

The limiting of an X-ray beam to the required size is known as collimation. The purpose of a collimator is to limit the useful beam to a desired area. The area exposed (that is, covered by the primary or useful X-ray beam) should never be larger than the film size used. In those cases where the anatomical part under study is smaller than the film, the X-ray beam must be further restricted (collimated) to the area of clinical interest [section 30308 (b) (3)]. In other words, the useful beam should be limited to the smallest area practicable and consistent with the objectives of the radiologic examination. Since in most instances the X-ray beam should be smaller than the film size, the ratio of X-ray beam area to film area should be less than one. The total amount of radiation received by a patient during radiography is chiefly affected by the area exposed.

The most efficient method of collimating the useful X-ray beam to the desired area is the use of the variable rectangular adjustable collimating device to restrict the size and shape of the X-ray beam. Other devices such as cones, cylinders or diaphragms should be used for specific examinations only.

Most collimating devices are equipped with a light localizer, which provides a visual indication of the size and location of the X-ray beam at any distance (see Figure 7).

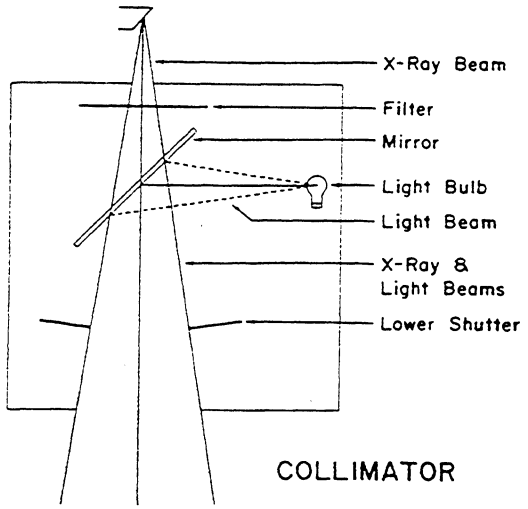

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Figure 7. Alignment of light and X-ray beams.

Collimating devices have an important function to perform in addition to limiting patient dose – they improve the contrast and detail of the radiographic image by reducing the amount of scattered radiation reaching the X-ray film. Therefore, it is vital to properly employ collimating devices at all times and to collimate/restrict/limit the X-ray beam to the area of clinical interest only. The X-ray field should never be larger than the size of the film used.

Failure to collimate an X-ray beam to the area of clinical interest represents not only one of the most frequent causes of unnecessary patient radiation dose but also constitutes the **largest** contribution to unnecessary patient radiation dose. X-ray personnel should remember that doubling the exposure area by opening the collimator will double total patient **integral dose**.

4. Tabletops and vertical cassette holders.

The aluminum equivalent of the tabletop when a cassette tray is used under the tabletop, or the aluminum equivalent of the front panel of the vertical cassette holder, may not be more than 1 millimeter at 100 kVp [section 30308 (a) (9)].

B. ACCESSORIES.

1. Gonad shields and gonad shielding.

The main reason for protecting the gonads is to reduce birth defects (genetic damage) in offspring of future generations. The male gonads (testes) can be shielded during many abdominal X-ray examinations without obscuring features of diagnostic interest. **Gonad shields for male patients must be used for examinations of hips, pelvis, and upper femur, unless your X-ray supervisor specifically requests that gonad shielding not be used.**

The ovaries are situated in the abdomen at varying depths and levels in female patients. Shielding ovaries can frequently interfere with diagnosis. However, **whenever possible, you should use appropriate ovarian shielding. Various designs of ovarian shields are available from commercial manufacturers.**

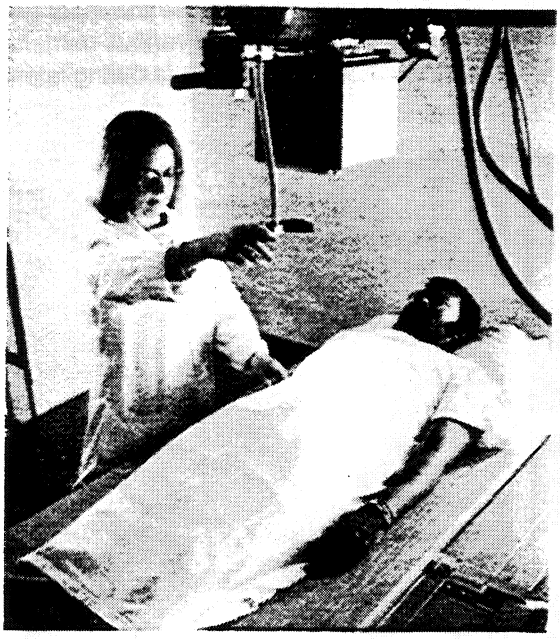
You should be especially careful in taking chest X-rays on pregnant patients. In such instances you should shield the patient's abdomen from front and back with a wrap-around lead apron of at least 0.5 millimeters lead equivalent to protect the fetus. Your X-ray supervisor must give you policies that describe when to use and when not to use testicular or ovarian shielding.

The use of 0.5 mm lead equivalent sheet of lead to protect gonads reduces gonad dose by approximately 92 percent. The testes/ovaries under a lead sheet gonad shield can receive internally scattered radiation up to about five percent of the incident primary X-ray beam even from chest or skull X-ray procedures.

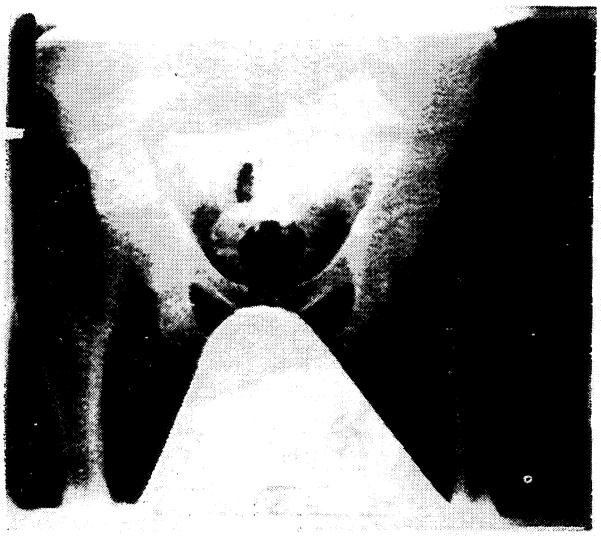
SUITABLE GONAD SHIELDS.

a. Shadow shields.

A shadow shield consists of some radiopaque material, suspended over the patient's body to cast a "shadow" in the primary or useful X-ray beam over the area of the testes or ovaries. There are commercially available shields which can be attached to the X-ray tube head. Since the shadow shields are attached to the X-ray tube housing, they are always available for use and can be used without any embarrassment to the patient or the radiologic technologist. However, proper positioning of the patient is essential as is the accurate alignment of the X-ray beam-defining light. Also, you must remember to move the shadow shield out of the X-ray field after use.



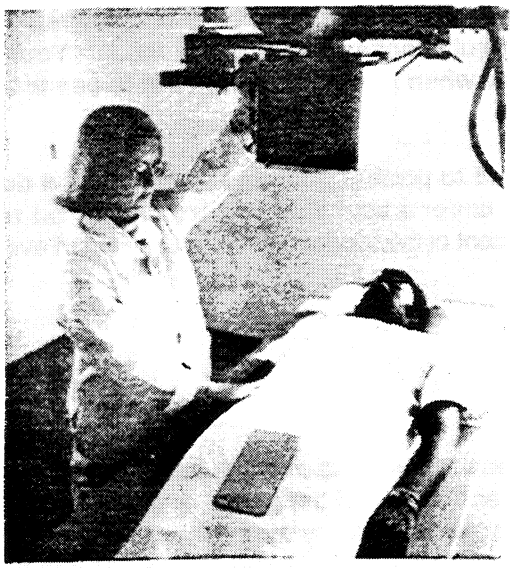
Positioning a shadow shield



Radiograph showing use of shadow shield

b. Flat contact shields.

The flat contact shields consist of uncontoured, lead-impregnated material, placed on or taped to the patient to cover the gonads. This type of shield is most effective for AP or PA views where the patient is recumbent.

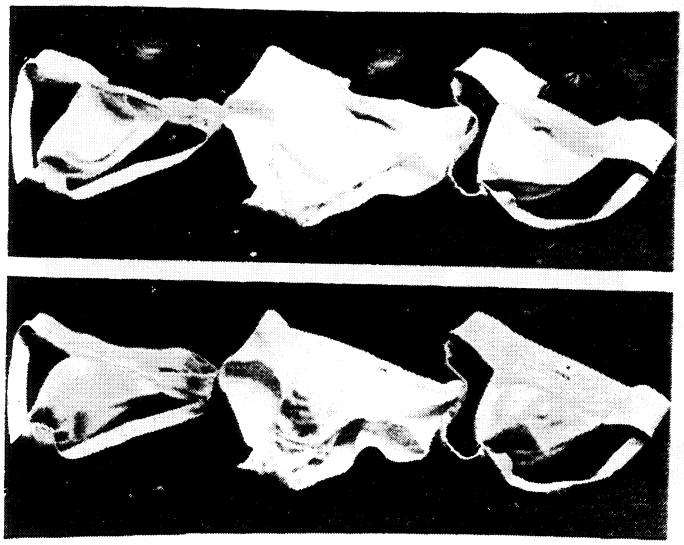


Example of flat, contact shield use

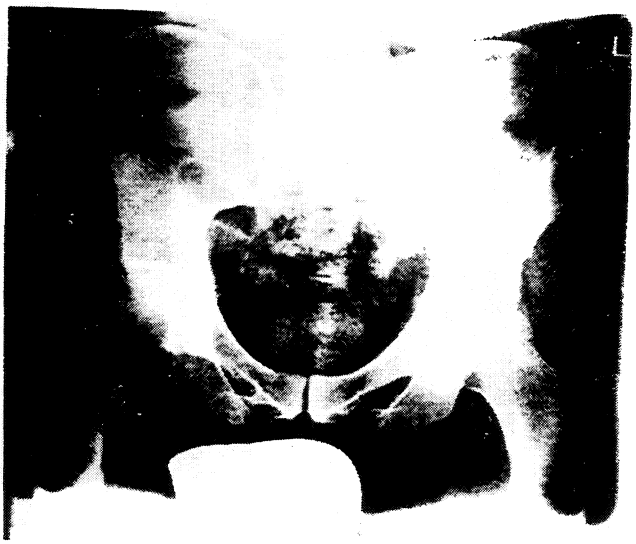
Radiograph showing use of flat, contact shied

c. Shaped contact shields.

The shaped contact shields consist of radiopaque material contoured to enclose the male gonads. Shaped contact shields are commercially available that can be contained within various carriers such as athletic supporters. This type of shield offers effective protection to male gonads during lateral and oblique projections or views as well as AP view.



Examples of shaped, contact shields with various carriers



Radiograph showing use of shaped contact shields

You must remember that gonad shielding may not be less than 0.5 mm lead equivalent and you must shield or protect gonads of potentially procreative patients with appropriate gonad shields, when:

- **the patient is of a reproductive age**
- **the shield will not interfere with the examination/diagnosis**
- **the gonads are adjacent (within 5 centimeters) to the primary X-ray beam**

2. Grids.

A grid consists of a series of lead strips separated by radiolucent spacers. The function of the grid is to remove or absorb scattered radiation that emanates from the patient before it reaches the film (see Figure 8).

The only X-rays transmitted through a grid are those traveling in the direction of the interspace (non-interacting and small-angle scattered photons). X-rays scattered obliquely through the interspace are absorbed.

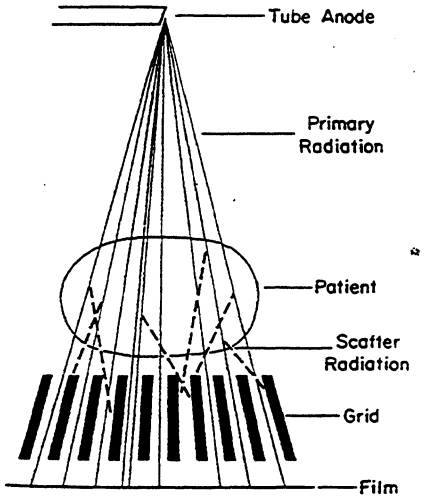


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Figure 8. Grid function.

Terminology:

Grid ratio: A grid ratio is defined as the ratio between the height of the lead strips and the interspace distance between them (see Figure 9, page 17).

Grid pattern: Grid pattern refers to the orientation of the lead strips on their longitudinal axis.

Linear grid: Linear grid is a grid in which lead strips are parallel to each other on their longitudinal axis (see Figure 10, page 17).

Focused and Non-focused grids: A focused grid is a grid made up of lead strips that are angled slightly so that they focus at some distance (see Figure 11, page 17, and Figure 12, page 18).

A parallel grid is a grid in which the lead strips are parallel when viewed in cross section.

Stationary and moving grids: A stationary grid is a nonmoving grid.

A Bucky grid is a moving grid. It has the advantage of eliminating grid lines on the film image but the disadvantage of increasing patient radiation dose more than the use of comparable grid ratio stationary grids.

Grid cutoff: There are four conditions that may result in grid cutoff (see Figure 13):

- o Upside down grid
- o Crooked grid
- o Grid off center
- o Off focus grid

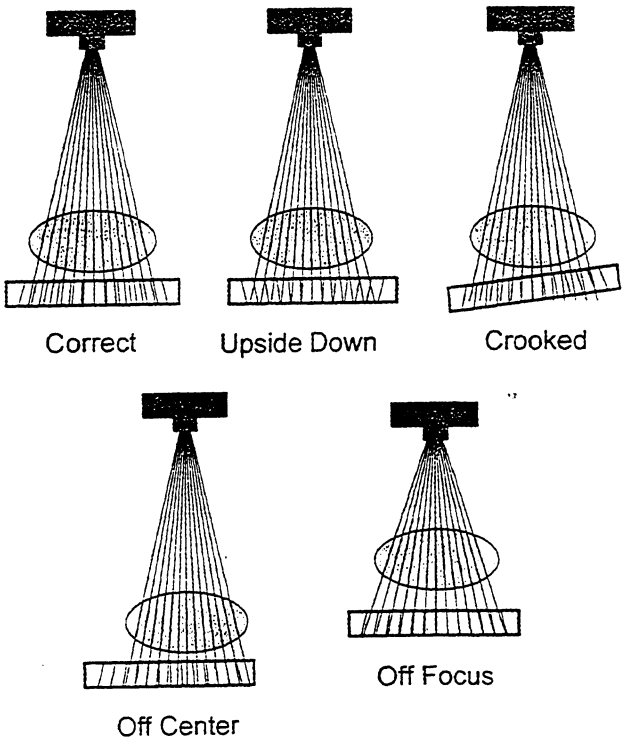

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Figure 13. Some of the situations that can lead to grid cutoff artifacts.

The use of grids, in conjunction with X-ray beam collimation, is necessary to remove scattered radiation with high kilovoltage techniques, particularly in the radiography of thick parts (measuring over 8 centimeters or 3 inches). However, the disadvantage of a grid is that its use increases patient radiation dose.

Grids with higher grid ratios remove the scatter better before scatter reaches the film than grids with lower ratios. However, there is a tradeoff because the higher the grid ratio, the greater the radiation dose to the patient. Therefore, a judicious compromise must be utilized to accommodate high kilovoltage and low milliamperage techniques used in modern radiology practice. As a general rule, grid ratios up to 8:1 are satisfactory at tube potentials below 90 kVp. **Grid ratios above 8:1, such as 10:1 or 12:1 are appropriate when the kVp used exceeds 90.**

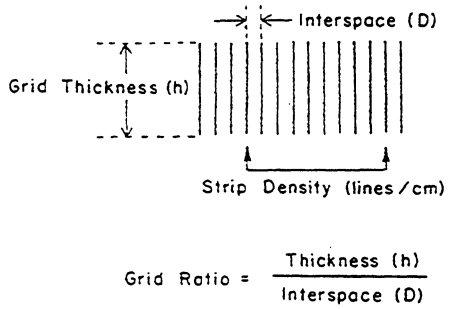

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Figure 9. The grid ratio is defined as the thickness (height)of the grid strip (h) divided by the thickness of the interspace material (D).

Linear grids (parallel strips) (see Figure 10) are frequently used with general radiographic examinations at non-standard distances (more than 40 inches or less than 40 inches).

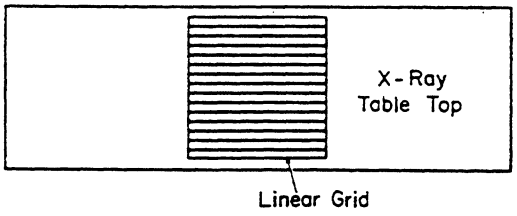

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Figure 10.

Most grids used in radiologic practice today are focused grids (slightly angled strips). A focused grid is made so that the grid strips are coincident with the primary X-ray path across the entire film (see Figures 11, and 12, page 18). These types of grids are most frequently used in fixed geometries to ensure proper positioning within the focal range.

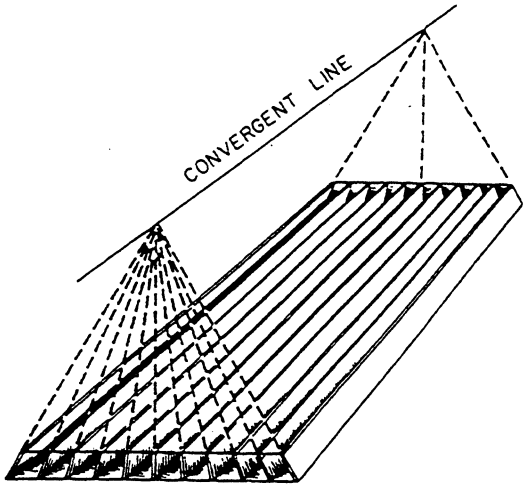

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Figure 11. Focused linear grid.

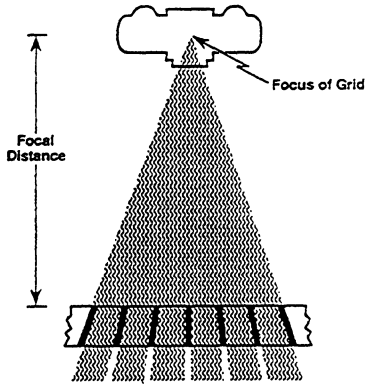

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Figure 12. Focused grid.

Grid uses: **Linear grids:** Most X-ray tables are equipped with linear grids. Their major advantage is that they allow the X-ray tube to be angled along the length of the grid without a loss of primary radiation from grid "cutoff."

As stated before, grids improve radiographic quality by reducing the amount of scattered radiation that would reach the film. The main drawback to the use of grids is increased patient radiation dose.

3. Cassettes.

A cassette is thin, rigid, light-tight X-ray film holder containing intensifying screens mounted within front and back structures (covers) that are hinged together (see Figure 14).

a. Cassette fronts.

The cassette front cover (the side facing the X-ray tube) must be made of a material with low-absorption to X-rays such as carbon fiber, cardboard, plastic (Bakelite), or aluminum. These materials allow the X-rays to more easily penetrate the cover.

Cross-sectional view of cassette containing front and back intensifying screens and loaded with double-emulsion film.

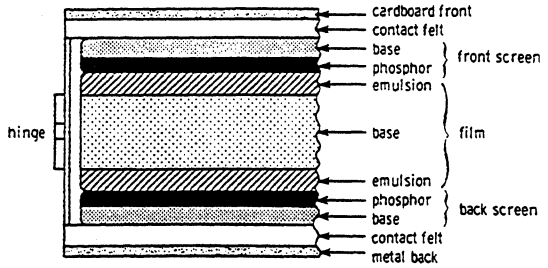

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Figure 14. Cross-sectional view of cassette containing front and back screens and double-emulsion film.

b. Intensifying screens.

An intensifying screen is a device that converts the energy of the X-ray beam into visible light. The visible light then interacts with the X-ray film, forming the latent image. Intensifying screens resemble thin cardboard or plastic sheets that are made in sizes to match those of radiographic film.

Radiographic film is usually sandwiched between two intensifying screens which are permanently fixed to the inside of the cassette and thus are a permanent part of the cassette (see Figure 14, page 18). Nearly all X-ray examinations, other than those of extremities measuring below 8 centimeters, are made using intensifying screens.

About 30% of the X-rays which hit the intensifying screen actually interact. Each interaction produces a large number of visible light photons which cause the film to darken during film development. As much as 95 percent of the darkening of the film results from light produced by the intensifying screens. Thus, when using film alone without intensifying screens, more X-rays (20 to 50 times is typical) must be generated to produce an acceptable image, resulting in a dramatic increase in patient radiation dose.

Since intensifying screens are used to **reduce the patient radiation dose**, one beneficial characteristic is the magnitude of dose reduction obtained, a property called the **intensification factor**, which measures the "speed" of the screen. The intensification factor is calculated by exposure without screens divided by exposure with screens.

Ideally, a film-screen combination should be selected for the type of examination to be conducted to combine detail rendition and sensitivity for optimum information content.

Rare-earth intensifying screens are replacing the once prevalent calcium tungstate screens. Rare-earth screens provide comparable image quality to calcium tungstate screens, while reducing patient dose from between two to five times. Therefore, from the radiation protection point of view, rare-earth intensifying screens are advantageous. Best results are achieved with specific rare-earth screen - film combinations, such as those available for blue film, green film, and high and low kVp applications.

For comparison purposes, medium speed calcium tungstate screens are arbitrarily assigned a "speed" of 100. "Speed" values are approximations for calculating exposure adjustments required to match radiographic density. For example: Changing from medium-speed calcium tungstate screens (speed of 100) to regular rare-earth screens (speed of 400) will result in a reduction of 75 percent in the exposure settings and patient dosage required for the same density of the radiographic film of comparable diagnostic quality (see Appendix 6, page 77, for Relative Speeds of Intensifying Screens).

Care of intensifying screens and cassettes.

Screens and cassettes require special, careful handling, as they can be easily damaged. Cassettes may become bent or warped if they are dropped or improperly stored. The use of such warped cassettes will produce localized unsharpness on the finished radiographs. Even a small fingernail mark may damage screens. The screens must be kept free of dirt, grime or scratches. Developer solution or cigarette ashes on the screens will definitely produce artifacts (light spots) on the radiographs. **An artifact is any density on a radiograph that is caused by something not belonging to the part being X-rayed.**

C. RADIOGRAPHIC/X-RAY FILM AND FILM PROCESSING.

1. Radiographic Film.

X-ray or radiographic film is a photographic film which is usually coated with an emulsion on both sides of the film base (see Figure 15, page 20). The light-sensitive material in the emulsion is a silver bromide crystal. Films must be stored in an upright position (never flat or leaning) because X-ray film is sensitive to pressure.

X-ray films have been designed to be most sensitive to light in the blue-violet spectrum for use with calcium tungstate intensifying screens or to the blue-green spectrum for use with rare-earth intensifying screens. Light or X-ray exposure causes the grains in the emulsion to develop an invisible (latent) image. The development/processing produces a visible pattern of black metallic silver on the finished radiograph.

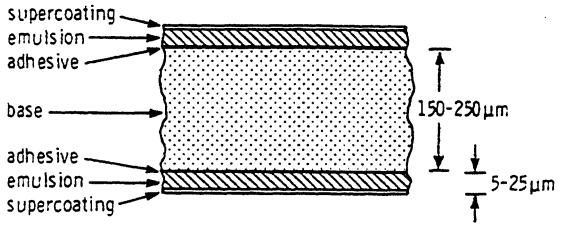

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Figure 15. Cross-sectional view of radiographic film. The bulk of the film is the base. The emulsion contains the diagnostic information.

The screen films for routine radiography are always double emulsion and are designed to be used with a pair of intensifying screens. In this case, X-rays produce light (fluorescence) when interacting with the phosphor substrate. This fluorescence in the screens exposes the film. The screen film used should correspond to the type of intensifying screens used (rare earth or calcium tungstate).

Examinations taken with intensifying screens reduce the radiation dose of the patient by approximately 95 percent compared to examinations conducted without intensifying screens.

Film speed is a measure of the film (or film within a film/screen cassette) darkening with radiation exposure. Films are rated by relative "speed" number, that is, 1 for slow speed, 2.5 for intermediate speed, and 10 for high speed. The amount of radiation required to darken a film is proportional to the reciprocal of the relative speed number: Speed (S) is defined as the reciprocal of the radiation dose in rads required to produce a density of 1.0 above base and fog densities.

$$(S) = \frac{1}{R}$$ "R" is the relative speed number

For example, if an intermediate speed film is replaced by a high-speed film, the X-ray exposure to the film and patient necessary to obtain a given film density is:

$$\frac{1/10}{1/2.5} = 0.25 = 25\%$$ as much as when intermediate speed film is used

Therefore, $\frac{100 - 25}{100} = 0.75 = 75\%$ reduction in patient radiation dose using the faster film

2. Optimum Film Developing/Processing Techniques.

Even the best X-ray equipment and careful selection of primary exposure factors will not produce satisfactory radiographs unless the darkroom equipment, film handling and film processing techniques are comparable in quality and precision. The darkroom should be properly designed and constructed.

The darkroom should be inspected for light leaks periodically. The **safelight** should be carefully selected to match the film manufacturer's specifications and should be used only with a lamp of the specified wattage in order to avoid film fogging. Films should never be handled with wet or moist hands or moved rapidly (to avoid formation of static marks).

The processing solutions should be kept fresh and maintained at adequate strength (concentration). Their temperatures should be regulated as recommended and an adequate water supply should be ensured. At least once a day, preferably at the beginning of the work day, a "sensitometric" strip (see page 96) should be passed through the film processor to allow measurement of fog (development of unexposed film which does not contain a latent image), speed, and contrast. In general, the manufacturer's recommendations should be followed.

There are two main advantages to automatic processing (see Figure 16). First, the time required to process a finished radiograph with an automatic processor is considerably reduced, from approximately 60 minutes for the full cycle for hand/manual film developing/processing to as short as 90 seconds for automatic processing. Second, if the automatic processor is maintained as recommended by the manufacturer and the chemicals are properly replenished, the uniformity or reproducibility of development will be greater and the quality control of films easier. The likelihood of error in hand/manual processing is much greater than for automatic processing.

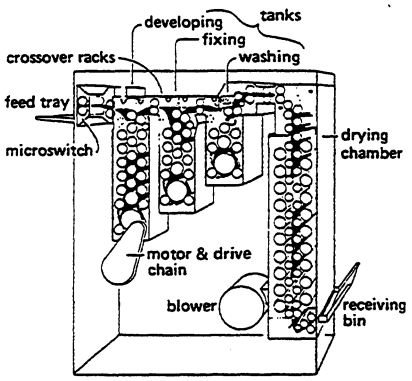

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Figure 16. A cutaway view of an automatic processor with the major components identified.

D. PRIMARY FACTORS AND TECHNIQUE CHART.

1. Kilovoltage (kVp).

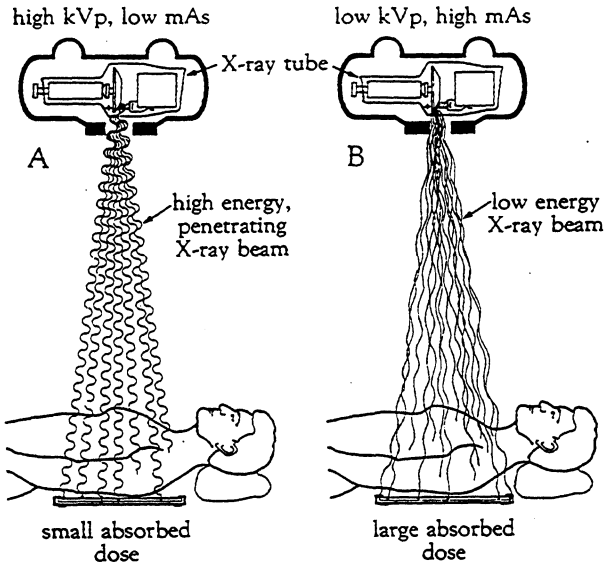
Producing high-quality radiographs largely depends upon proper selection of kilovoltage peak (kVp), so that the effective X-ray energy will result in maximum differential absorption by the tissue. Overall, high kVp techniques tend to reduce patient dose as the improved X-ray beam quality allows the use of lower X-ray tube current (milliamperage - mA) (see Figure 17, page 22).

Differential absorption of the various tissues increases as the kVp is lowered, but lowering kVp results in increased patient dose, assuming, of course, that all other factors such as distance, use of grids, etc., remain constant.

Since subject contrast is decreased with increasing kVp, an optimum kVp exists for a given procedure with a particular image-receptor system. Increase in kVp beyond an optimum range can lead to poor subject contrast or to an undesirable long, gray scale contrast.

Although increased kVp decreases the patient's skin dose, the higher energy photons that are scattered internally can travel farther prior to their complete interaction with the tissue of the body. This results in a slight, but measurable, increase in internal organ dose but is more than compensated by the marked reduction in patient skin dose.

The use of higher kilovoltage (kVp) and lower milliampere-seconds (mAs) reduces patient radiation dose. In (A), the use of high kVp and low mAs results in a high energy, penetrating X-ray beam and a small patient absorbed dose. In (B), the use of low kVp and high mAs results in a low energy X-ray beam most of which is absorbed by the patient (see Figure 17).



Reproduced, by permission, from Mary A. Statkiewicz et al: **Radiation Protection for Medical Radiography**, 2nd ed., 1993, by Year Book, Inc., St. Louis, Missouri, pg. 183.

Figure 17.

Some of the advantages of the high kilovoltage (kVp) technique are:

- **Reduced skin entrance radiation dose to the patient**
- **Shorter exposures, which lessen the chance for motion blurring of the image**
- **Increased radiographic latitude**
- **Improved control of radiographic contrast**
- **Less heat impressed into the X-ray tube because of greater X-ray production efficiency at higher voltages**

2. Milliampere-Seconds (mAs).

The quantity/amount [measured in milliampere-seconds (or mAs)] of X-rays produced is directly proportional to the milliamperage (mA) and time [measured in seconds or a fraction of second (s = time)] selected.

Tube current (mA): The tube current or mA control determines the rate of electron flow across the X-ray tube from the cathode to the anode and consequently the rate of X-ray production. The mA (current) determines the **quantity** of X-rays delivered per unit of time.

Time control: The time control determines the length of time X-rays are produced. The choices of mA and time directly influence radiation dose to the patient. Doubling either the milliamperage or exposure time doubles the radiation dose to the patient. Each factor (milliamperage and time) has to be carefully considered separately and in combination in order to keep patient radiation dose to a minimum while producing an image of good diagnostic quality.

Phototiming.

The main cause for retaking a film is improper selection of primary exposure factors such as kilovoltage (kVp) and milliampere-seconds (mAs), that is, the film is too dark or too light. Any repeat radiograph doubles patient radiation dose. The desired degree of film darkening and the corresponding density and contrast can be controlled by the use of automatic timing equipment or phototiming. The use of phototiming ensures uniform image quality and keeps the patient radiation dose at a minimum. Phototimers measure the amount of radiation passing through the patient and automatically terminate the exposure when the desired amount of radiation is obtained (see Figure 18). This is done with either a photomultiplier or an ionization chamber sensing device.

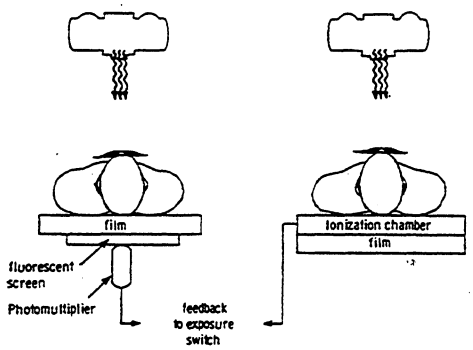


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Figure 18.

Contrary to popular belief, phototimers do not negate the skill of the technologist; in fact, technologists must be very careful to position the patient and collimate the useful X-ray beam uniformly and correctly in order to get the necessary images within the radiation exposure limits. Also, periodic recalibration of phototimer by a qualified individual is mandatory.

3. Target-to-Film/Source-to-Image Receptor and Target-to-Skin Distance.

When a fast-moving stream of electrons hits a tungsten "target", X-rays are produced (see Figure 1, page 7). The target is the origin of the X-ray beam. X-rays then must enter a patient, emerge from the patient and expose the film (see Figure 8, page 15). The produced images on the radiograph are larger than the objects they represent, a condition called magnification (see Figure 19). Many objects also exhibit distortion, unequal magnification of different portions of the body area being X-rayed (see Figure 20, page 24). Therefore, use of an optimum target-to-film distance is as essential as is the placement of the object as close as possible to the film.

It has been established that a 40-inch target-to-film distance is optimal for most radiographic examinations. The most notable exception occurs in chest radiography, where a 72-inch target-to-film distance is utilized in order to diminish the magnification of the heart shadow on the radiograph, and radiography of the lateral cervical spine to reduce the effects of a large part-film distance. Shorter distances than 40 inches sometimes are used with extension cones for sinus and similar skull radiography work.

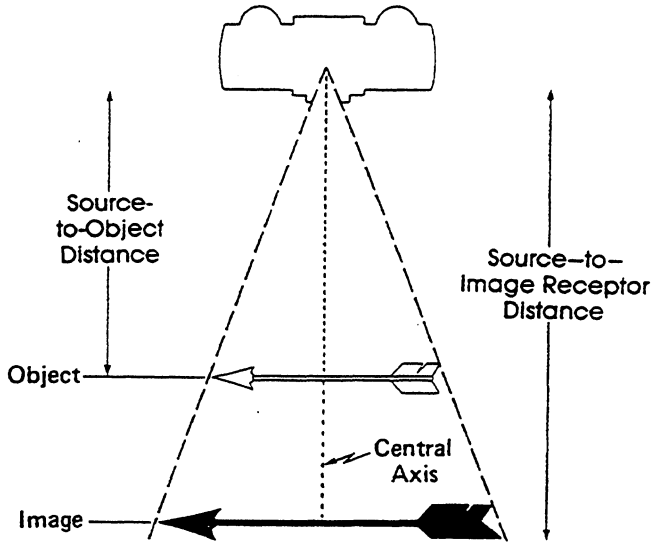

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Figure 19. Magnification can be measured by the ratio of image size to object size.

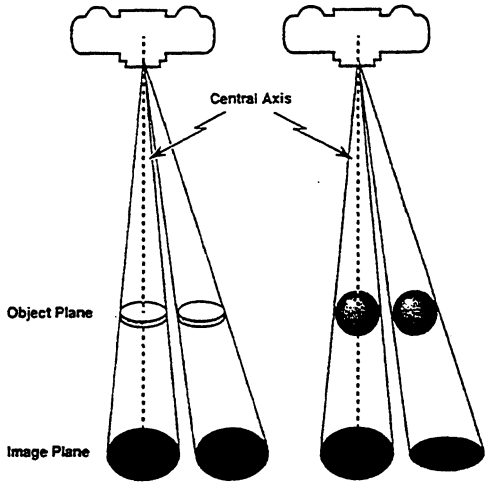

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Figure 20. Object shape influences distortion.

The need for using correct target-to-film distance is illustrated by the following example:

Exposure I = 350 millirads skin radiation dose; Exposure II = ?

Distance D1 = 40 inches; Distance D2 = 38 inches

Calculating the exposure difference using the inverse square law formula (see Appendix 2, page 71 for Time - Distance - Shielding) will show that Exposure II = 388 millirads. The difference is 38 millirads 11 percent **increase** of skin radiation dose if the distance is decreased by only 2 inches (5 percent) - from 40 inches to 38 inches!

4. Technique Chart.

Techniques employed should be those that achieve the desired objectives with a minimum dose to the patient. As a general rule, the radiation dose to the patient must be kept to the practical minimum consistent with clinical objectives.

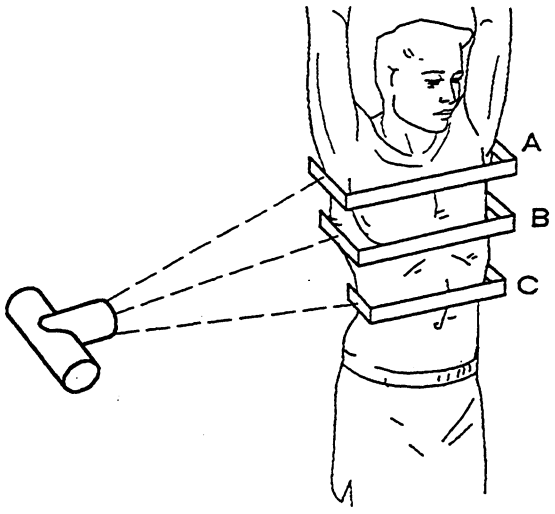
The selection of technical factors is usually done by X-ray personnel. The determination of technique factors based on thickness measurements will provide good results in a very high percentage of cases.

Basically, there are only three controls on the X-ray machine:

- **The kilovoltage (kVp) control**, which determines the maximum high voltage applied across the X-ray tube from the cathode to the anode
- **The tube current (mA) control**, which determines the rate at which electrons flow across the X-ray tube
- **The timer**, which determines the total time during which X-rays are produced

An appropriate technique chart must be available to all radiologic technologists. Technique charts are available from X-ray equipment or film manufacturers, upon request from the Radiologic Health Branch (see address on page 69), or may be constructed in various forms by X-ray personnel themselves. These technique charts are designed to aid the X-ray personnel in selecting appropriate values of **primary factors such as kilovoltage, milliamperage, distance, and exposure time for each radiographic examination.** All technique charts are based on the different densities of various body parts and on different thicknesses (measured in centimeters with a **caliper)** of the same part of the body of different individuals.

Technique charts are based on the precise measurement of the body part being X-rayed; therefore, correct measurement with a caliper is essential. **The caliper should be placed on the part where the central ray (CR) enters and exits the body. The central ray (CR) is the center of the bundle of primary X-rays coming from the X-ray tube.**



Reproduced, by permission, from: Richard R. Carlton and Arlene McKenna Adler, **Principles of Radiographic Imaging**, Delmar Publishers, Inc., New York, 2nd ed., 1996, pg. 463.

Figure 21. Proper caliper measurement of the lateral chest is by placing the caliper at position B.

It should be remembered that the technique chart is only a good starting point. Approximately 10 to 25 percent of cases will require minor adjustments, and up to 10 percent will require major technique adjustments.

In the final analysis, it is up to the radiologic technologist to optimize techniques, taking into consideration anatomical abnormalities, any disease process, the patient's age, height, weight, and physical condition.

When converting from standard intensifying screens to rare-earth screens one should keep in mind that the rare-earth screen/film combinations do not produce a linear response to all photon energies. There may be as much as a 2:1 difference in response as one goes from 90 kVp to 60 kVp. That is, while the existing techniques using 90 kVp can be cut in half when going from calcium tungsate to rare-earth (gadolinium oxysulfide) screens, this cannot be done for techniques using 60 kVp. The new technique chart should be made with the assistance of the film or screen manufacturers' representatives.

Each radiography supervisor should keep in mind that section 114850 (g) [old section 25661 (h)] of the Health and Safety Code makes him/her responsible for the technical aspects of all X-ray examinations and procedures performed under his/her jurisdiction.

E. PATIENT AND PATIENT POSITIONING.

1. Patient - human body.

The human body is made of muscle, fat, bone, air passages, and compartments of fluid. Therefore, different thicknesses of these components and different combinations of them will result in a differential absorption across the radiographic field. In other words, the production of a radiograph is a result of differential absorption of X-rays of different body structures being X-rayed.

Tissue density is the most important factor affecting attenuation, and radiographic image contrast is largely dependent upon differences in tissue density. Thus, high contrast between air and soft tissues is created entirely because of density differences. Disease processes alter densities; thus, an emphysematous patient will need less exposure that a patient who has pneumonia. Skin pigmentation does not influence exposure factors.

In passing through the patient, most of the photons will interact and will be absorbed by the tissue. Only about 5 percent of the incident photons will emerge from the patient unaffected (remnant radiation) and be used to form the radiographic image.

Increasing the radiation energies (kVp) increases the number of transmitted photons (and decreases attenuation). Increasing the density, atomic number, or electrons per gram of the section of the patient being examined, decreases the number of transmitted photons (and increases attenuation). For example, lung attenuation is less than surrounding tissue and therefore increases the amount of radiation transmitted to the X-ray film while bones with a higher density cause the opposite effect and decrease the amount of radiation transmitted to the X-ray film.

It should be noted that muscle and water have approximately the same density while fat has a density some 10 percent less than that of water. Bone, on the other hand, has the density nearly twice that of water and muscle.

The following chart shows comparison of physical characteristics of air, fat, water, muscle, bone, aluminum, and lead:

	Effective atomic number	Density (g/cm)	Abundance in human body (in percent)
Air	7.64	0.00129	
Fat	5.92	0.91	14.0
Water	7.42	1.00	
Blood	7.42	1.00	7.7
Bone marrow	7.42	1.00	4.2
Muscle	7.42	1.00	43.0
Organs	7.42	1.00	12.4
Subcutaneous tissue	7.42	1.00	5.8
Skin	7.42	1.00	2.9
Bone	13.80	1.85	10.0
Aluminum	13.00	2.70	
Lead	82.00	11.00	

Our discussion of attenuation has only dealt with primary radiation, which either passes through the patient unchanged or is completely removed from the useful X-ray beam. Only that part of the X-ray beam which has gone through the patient and reaches the film (called remnant radiation) can produce a radiograph with proper density, contrast, and detail and thus provide diagnostic information. The primary radiation that exits the human body (remnant radiation) consists of noninteracting and small-angle scattered photons and carries the X-ray image.

Motion unsharpness.

Motion unsharpness in the image is caused by movement of the patient or the X-ray tube during the exposure. The primary methods of decreasing motion unsharpness are the use of short exposure time and the use of patient-immobilization devices. Clear instructions to the patient are essential as well.

2. Absorption and Scatter.

The scattered photons (sometimes called secondary radiation) resulting from the Compton effect radiate in all directions. This effect is the only process that takes place at kilovoltages above 80 for soft tissue. Below 80 kVp the photoelectric effect predominates.

When an X-ray photon interacts with matter (including the human body), it is either absorbed and removed from the beam or scattered into a different direction (and possibly toward the detector). The absorption event probability, called photoelectric absorption, is strongly dependent on the atomic number of the interacting medium and the energy of the X-ray photon beam. The probability of absorption is greater for high atomic number material [that is, lead (Z=82), iodine contrast (Z=56), bone calcium (Z=40)] than for soft tissue or air (Z=7). Also the photoelectric effect is much greater for low energy X-rays than for high energy X-rays. At higher energies, the probability of Compton interaction (see Glossary) increases and becomes the predominant mode of X-ray interaction. This scattered radiation is more or less isotropic in direction -- as a result, a large portion of scatter can actually reach the film/detector and contribute to a significant amount of film darkening without providing useful information.

Scattered radiation from the patient is not as energetic as the incident X-ray photon. If an ionization chamber was located at right angles (90 degrees) and at a distance of one meter from the patient, the amount of exposure detected by the ionization chamber would be approximately 1/1000 from the incident radiation.

Another very important factor in the quality of the final image is scattered radiation from the patient (part being X-rayed). Frequently, more than 50% of the total number of photons reaching an X-ray film is from scattered radiation. It detracts from film quality and contributes no useful information but it does add to the blackening of the film (film fogging).

Four factors determine the quantity of scatter radiation:

- **Kilovoltage (kVp)**
- **Part thickness**
- **Field size/area exposed**
- **Tissue density**

Scatter radiation is greatest with high kVp techniques, large fields, and thick body parts which, unfortunately, is what we usually deal with in diagnostic radiology. Field size is the most important factor in the production of scattered radiation. A small X-ray field irradiates only a small volume of tissue and generates only a small number of scattered photons. As the X-ray field is enlarged, the quantity of scattered radiation increases rapidly and then gradually reaches a plateau (equilibrium is reached).

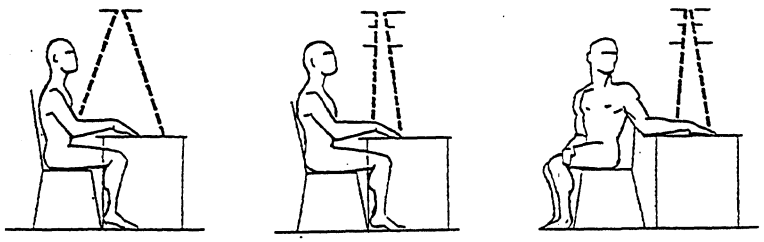
When an X-ray beam reaches the patient, it contains no medical information. After a beam passes through and interacts with the tissues in the part examined, it contains all the information which that particular radiographic examination can possess (consisting of noninteracting and small-angle scattered photons). This information is represented by variation in the number of X-ray photons in different areas of the emerging beam. We are unable to make direct use of the information in this form and must transfer it to radiographic film. The technical factors utilized in conducting a radiographic examination represent compromises between image quality and patient exposure. Each factor will never be optimal for all considerations at once.

3. X-ray Beam -- Part Being X-rayed -- Film Alignment.

Each radiographic X-ray tube head should be provided with a mechanism to assure proper alignment of the X-ray beam and the film (see Figure 7, page 12). It does no good to align the light beam and the X-ray beam but have the film partly out of the X-ray beam.

A thoughtless alignment of the primary X-ray beam directed toward or near the gonads often occurs in studies of the upper extremities with the patient seated at the end of the table upon which the hand or wrist is positioned.

The following illustration shows protection of the patient by positioning:



Gonad dose ratios: 90 millirads 0.5 millirads 0.03 millirads

F. ANCILLARY FACTORS.

1. X-Ray Generator Design.

X-ray generators supply electrical power to the X-ray tube. There are certain technical advantages of three-phase and medium/high frequency generators over the single-phase generators (see Figures 22, 23):

- o Near constant potential is available
- o High mA is available for very short exposures, which is useful in angiography or uncooperative patients (that is, pediatric)
- o Higher effective kV

However, from the standpoint of patient dose and radiographic quality (when radiographic technique is adjusted to same density and contrast), there is no appreciable improvement with the three-phase or medium/high frequency generator in standard imaging techniques.

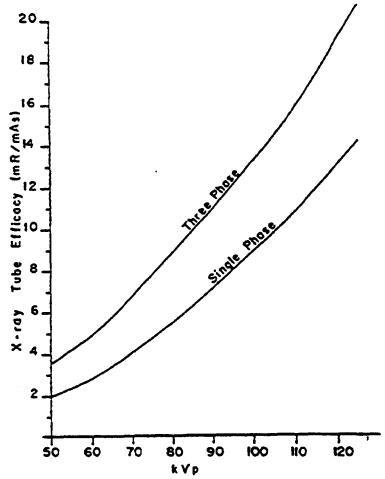


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Figure 22. Typical X-ray tube efficacy values.

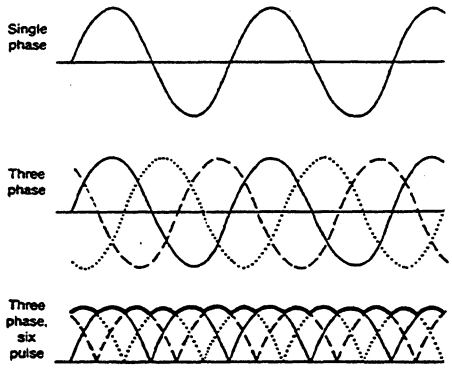

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Figure 23. Voltage waveforms for single phase and three phase rectification.

Three-phase power is a more efficient way to produce X-rays than is single phase.

SUMMARY

It should be possible to reduce patient and operator radiation dose and still obtain a satisfactory radiographic image for viewing purposes by fulfilling the following conditions:

- Restrict or collimate the size of the exposure field to the area of clinical interest only
- Use patient shielding, particularly for such areas as a fetus, gonads, lens of the eye, thyroid gland, and active blood forming organs such as spleen and bone marrow
- Use caliper and consult technique chart for proper selection of the primary factors (kilovoltage, milliamperage, time, and distance) and other factors that influence production of good quality radiographs
- Use the lowest milliamperage and highest peak kilovoltage technique possible for the particular examination
- Utilize the best available film-screen combination, that is, high speed and rare-earth intensifying screens
- Avoid film fogging by the following:

  --using proper safelight
  --not exposing the film to ionizing radiation in the film storage area
  --not processing films in a contaminated developer
- Keep the patient-film distance to a minimum
- Employ correct film processing techniques
- Employ correct focal-spot to film distance. Usually for radiographic examinations it is 40 inches, except for chest and lateral cervical spine radiography that requires a focal-spot to film distance of 72 inches.
- Be especially careful when X-raying infants, children, pregnant women and persons of reproductive age.

It is your responsibility and duty to produce radiographs which provide maximum diagnostic information with a minimum of radiation dose to the patient and others.

CHAPTER III

REPEAT FILMS (RETAKES)

A repeated radiograph/X-ray is known as a "retake." Reasons for retakes can be divided into two categories:

A. Equipment and accessory failure, malfunction or error.

B. X-ray personnel error.

A. EQUIPMENT AND ACCESSORY FAILURE, MALFUNCTION OR ERROR.

Equipment and accessory failure, malfunction or errors are referred to as "technical errors" or "hardware errors" and include the following:

- o Inaccurate kilovoltage (kVp) calibration
- o Inaccurate milliamperage (mA) calibration
- o Inaccurate timer calibration
- o Inaccurate automatic exposure control (AEC) response
- o Dirty or damaged cassettes
- o Improperly labeled or damaged grids
- o Malfunctioning collimators
- o Improper film storage
- o Incorrect or inconsistent film processing

B. X-RAY PERSONNEL ERROR.

X-ray personnel errors include all of the following:

- o Use of incorrect technical factors (kilovoltage, milliamperage, distance, time)
- o Incorrect positioning
- o Failure to measure the patient with caliper
- o Improper collimation
- o Improper use of accessories such as grids, cassettes
- o Improper handling of unexposed or exposed films
- o Failure to communicate clearly to the patient to hold the breath or to hold still

Experienced X-ray personnel do not repeat more than 2 percent of the examinations while inexperienced or careless X-ray personnel repeat 10 percent or even more of all the radiographs they take.

Retakes not only unnecessarily contribute to patient dose but add to the expense of the films, additional use of X-ray personnel time, add wear and tear on the equipment and accessories, and inconvenience the patient.

C. REPEAT FILM/RETAKE STUDIES.

Studies regarding retakes show that approximately **50 percent of retakes are due to error in exposure factors** (the resulting film or radiograph is either too dark or too light, that is, the film has incorrect density or shows poor contrast). **Positioning errors account for approximately 25 percent of all retakes.** Other reasons for retakes have been:

- Motion (respiratory or other) (11%)
- Film processing errors (6%)
- Wrong examination, wrong projection, multiple exposures (4%)
- Improper X-ray beam-film alignment (3%)
- Screen, cassette, grid errors (3%)
- Foreign objects (1%) and other reasons (2%)

The frequency of retakes by body areas under examination were as follows:

- Spine - 32% (cervical - 7%; thoracic - 17%; lumbar - 8%)
- Hips and pelvis - 8%
- Extremities - 13% (upper extremities - 8%; lower extremities - 5%)
- Chest - 5%
- KUB/abdomen - 12%
- Ribs and sternum - 8%
- Skull - 5%
- GI tract - 15% (cholecystogram - 6%; upper GI series - 6%; barium enema - 3%)
- Other examinations - 2%

The abdominal region X-ray examinations (KUB, abdomen, lumbar spine, hips and pelvis, upper GI series, barium enema, and IVP) account for approximately 25 percent of all diagnostic X-ray examinations performed and repeat examinations of the abdominal region account for almost 40 percent of all retakes. These examinations are high bone marrow and high gonad radiation dose examinations; therefore, every effort must be made to keep the repeat rates of these examinations to a minimum.

D. SUPERVISOR RESPONSIBILITIES.

X-ray personnel position the patient, select technical factors, collimate the X-ray beam to the area of clinical interest, shield the patient, and process the films. Thus, by his/her actions X-ray personnel **directly** influence patient dose. However, **the holder of a Radiography Supervisor and Operator permit or a Radiology Certificate is responsible for everything X-ray personnel do regarding the conduct of the X-ray examinations and the quality of results**. When a poor radiograph is made, it is necessary to reexpose the patient to obtain a radiograph of diagnostic quality. Consequently, the first exposure was unproductive and, because the repeat film doubles the patient dose, the patient received an unnecessary amount of radiation.

The responsibilities of holders of Radiography Supervisor and Operator Permits or Radiology Certificates include all of the following:

(1) Ensuring that X-ray personnel have appropriate authorizations to use X-rays on human beings.

(2) Ascertaining that X-ray equipment is operated only by persons who have had adequate instruction in safe operating procedures and **who have demonstrated competence in the safe use of equipment** [section 30305 (b) (1), (2), and (3)].

(3) Ensuring that all X-ray equipment is in proper operating condition and appropriate for the procedures to be performed.

(4) Insisting that all X-ray personnel follow suggestions noted on page 34 and comply with the requirements noted in Supervision and Use of X-Rays on Human Beings (see page 61).

Supervisors should remember that section 107075 (old section 25692) of the Health and Safety Code states the following: "Any person who violates or aids or abets the violation of any of the provisions of this chapter or regulations of the department adopted pursuant to this chapter is guilty of a misdemeanor."

E. HOW TO MINIMIZE FILM RETAKES.

The production of quality radiographs is a complex process and involves satisfactory X-ray equipment operating performance, adequate quality accessories, well-trained and conscientious X-ray personnel, and, above all, adequate supervision.

The performance of X-ray personnel is influenced by many factors. Several generalizations are offered to X-ray Supervisor as potential means to minimize retakes:

(1) Employ only well-qualified X-ray personnel (holders of valid authorizations issued by the California Department of Health Services, Radiologic Health Branch) who have respect for their work and who conscientiously follow their assigned duties.

(2) Give counsel and assistance to X-ray personnel as needed. (Supervisors must understand the processes of radiologic technology.)

(3) Secure good equipment and accessories adequate for the examinations being performed. This is especially necessary when X-raying children.

(4) Recognize that X-ray personnel who are under pressure tend to take "shortcuts" and thus make careless errors.

(5) Provide for sufficient positioning aids such as radiolucent positioning blockers, sandbags, and similar accessories.

(6) Supervise X-ray personnel activities closely and, if indicated, offer or provide for additional training.

(7) Instruct X-ray personnel to follow these steps:

(a) Measure the thickness of the patient with calipers.

(b) Consult the technique chart.

(c) Set the technique factors.

(d) Position the patient.

(e) Instruct the patient.

(f) Expose the X-ray film.

(g) Process the exposed film or films.

F. REPEAT FILM/RETAKE ANALYSIS.

It is necessary to have an on-going retake analysis program. In order to reduce retakes, it is essential to make an assessment of the type of films and projections which are being repeated and to know the reason(s) why films are being repeated. This must be undertaken not only because of the monetary considerations, but, most importantly, in order to reduce patient radiation dose. The Radiologic Health Branch suggests the use of the forms found on pages 109 and 110 (see Appendix 15) for the retake analysis program.

Conducting retake analysis must be done judiciously and in such a manner as to minimize interference with the normal X-ray taking activities. Retake study results should never be used for disciplinary or personnel action.

CHAPTER IV

PEDIATRIC RADIOGRAPHY

The radiation doses received by children for radiographic examinations are generally less than those received by adults for an equivalent study. However, the longer life span of a child allows more time for manifestation of long term detrimental effects of radiation. In addition, as the law of Bergonié and Tribondeau (see page 47) suggests, children would generally be more sensitive to the effects of radiation since their tissues undergo higher rates of mitotic activity than those of adults. For these reasons, it is especially important to keep radiation doses to children to a minimum.

A. GONAD SHIELDING.

Gonad shielding of at least 0.5 mm lead equivalent must be used whenever possible when it does not interfere with the examination (see pages 12 - 15). The importance of utilizing gonad shielding for children cannot be stressed enough. The genetic effects of radiation are thought to be cumulative. Therefore, it is absolutely necessary to protect the child patients' gonads from radiation that may produce deleterious effects in their offspring.

B. ARTIFACTS.

It is important to remove all clothing, bandages and diapers from the area to be examined prior to radiography. These items may produce artifacts that degrade the diagnostic quality of the examination.

C. MOTION.

For children, motion accounts for more retakes than for adults. The use of short exposure times can aid in preventing repeat examinations. Also, whenever possible, establishing a friendly, nonthreatening rapport with the child in order to obtain optimum cooperation is worthwhile. In some cases, where long examination periods are necessary or when the examination itself is particularly uncomfortable, it may be necessary to use anesthesia or sedation. A child may be incapable of understanding instructions to remain motionless for the required period of time necessary for the examination. In such situations, the use of mechanical immobilization devices may be helpful.

Mechanical means of immobilizing or securing infants and children are available commercially or may be easily made. These devices range from simple boards with velcro straps to more complex positioning aids which move in a variety of angles and positions. The use of sandbags and compression bands has also been found useful.

D. PHOTOTIMERS.

Phototimers automatically terminate an exposure when an adequate image has been obtained. This is achieved by means of an exposure detection device which measures the amount of radiation reaching the X-ray film. (See Figure 18, page 23.) Phototiming equipment is particularly valuable for use in radiography of children since choosing the correct exposure factors is much more difficult for children than for adults. This is because more variations in children sizes are possible. It is important to note that phototimers will not function properly unless the part being radiographed covers the entire exposure detection device. Radiography of infants and very small children may therefore not be possible with equipment utilizing phototimers. When phototiming is not available or possible, technique charts must be carefully made based on size rather than age.

E. OTHER SPECIAL TECHNICAL CONSIDERATIONS.

1. Collimation.

Proper collimation is an extremely important technical consideration in the radiography of children. Even small increases in field size from the area of interest can dramatically increase the total radiation dose of the child since we are dealing with a smaller patient size. For children, it is important to collimate to the anatomical area of interest only and not to collimate to the size of the film. Manual override of automatic collimators may be necessary to achieve this end.

2. Grids.

Grids are not necessary when exposing infants due to the small volume being irradiated. The omission of grids can significantly decrease patient radiation dose. For larger infants and children, where grids are necessary but short exposure times and low kVp are utilized, low ratio, rapidly moving grids, or stationary fine line grids should be utilized.

3. Cassettes.

There are cassettes in which the front face is constructed of Kevlar which reduces the mA required for an exposure. The use of these cassettes can reduce the radiation dose of children when low kVps are used.

F. PERSONNEL AND PARENTAL PROTECTION.

Often, as in the case of premature or severely ill infants and children, when sterile conditions must be maintained, it is impossible to employ mechanical methods of immobilization and not medically practical to use sedation or anesthesia. In such cases, hospital personnel or preferably parents must physically restrain the infant or toddler during the radiation exposure. It is important to remember that the scattered radiation from these examinations is usually very low. However, leaded gloves and aprons must be worn by whomever holds the patient. Hospital personnel must not be frequently involved in patient holding. A parent or an individual who holds a patient must be carefully monitored and records of their exposure maintained.

CHAPTER V

COMPUTED TOMOGRAPHY (CT)

Computed Tomography (CT) is a unique diagnostic service that is different in many respects from that of other conventional radiographic examinations. As such, it warrants special consideration.

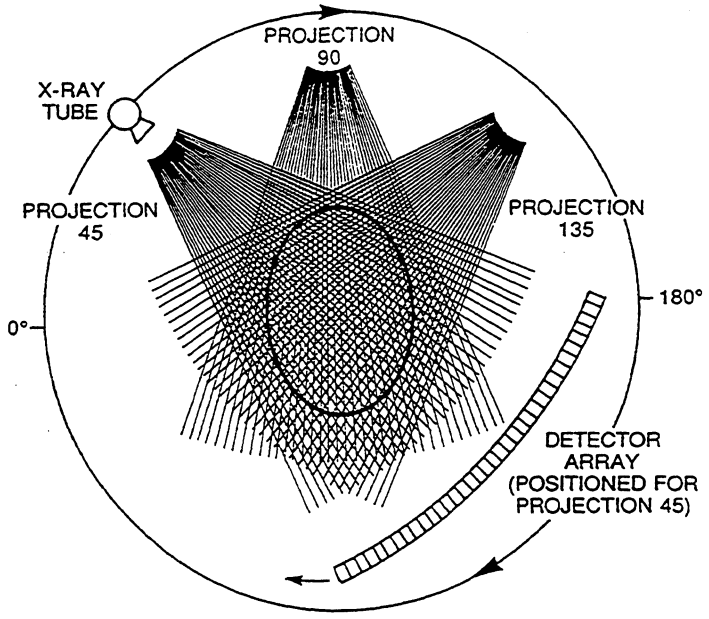
A. OPERATION.

Computed Tomography (CT) involves taking narrow X-ray fan beam images of multiple projections of an object and reconstructing the internal structure of the object with the aid of a computer program (see Figure 30, page 40). The CT image is not recorded like any other radiographic or fluoroscopic images. Instead, it has detectors that feed their response from the X-ray beam directly to the computer.

Computed Tomography has undergone many changes since its inception. Currently third and fourth generation scanners are in use (see Figures 24 and 25, 26, page 38). Third generation scanners have a "rotate-rotate" geometry. That is, the X-ray tube and detectors rotate about the patient to collect "views" of the anatomy from many angular positions (see Figure 24). In fourth generation scanners, a "stationary rotate" geometry is used. A fixed ring of detectors completely surrounds the patient, and only the X-ray tube moves around the patient (see Figures 25 and 26, page 38).

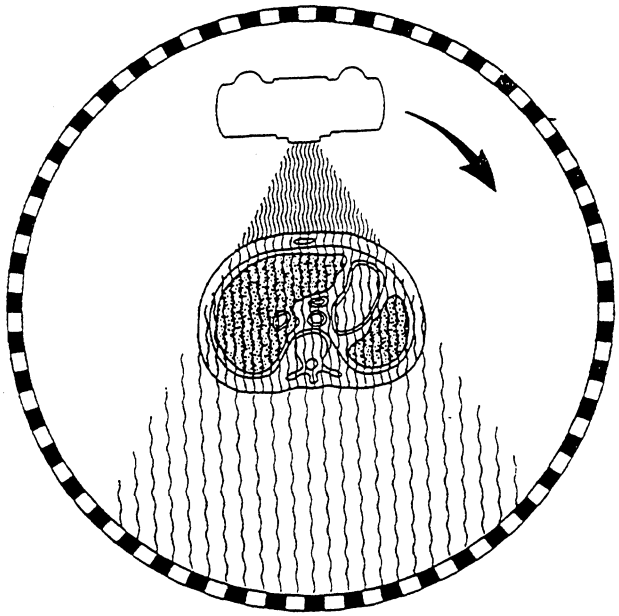
Third and fourth generation scanners provide similar image quality and deliver a similar dose to the patient.

CT scanners are subject to all of the quality assurance considerations of conventional radiographic units. In addition, the constant motion that the X-ray tube undergoes during examinations results in more instability of the system. Thus, a rigorous quality assurance program must be followed to maintain good image quality.



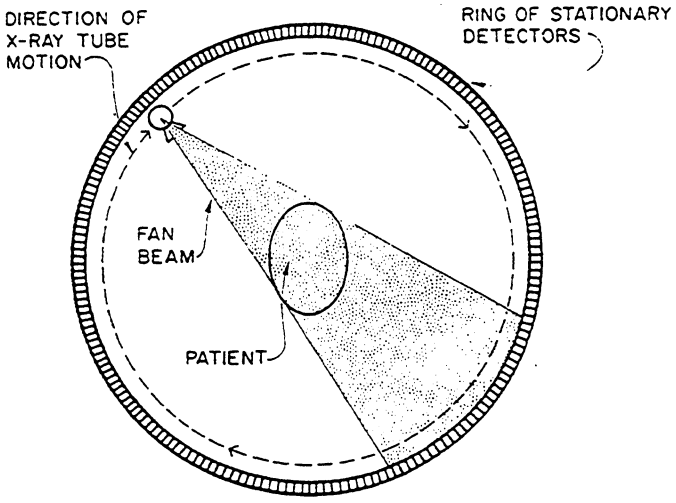
Reproduced, by permission, from Thomas S. Curry III, M.D., et al: **Christiansen's Introduction to the Physics of Diagnostic Radiology**, 4th ed., Lea & Febiger, Philadelphia, 1990, pg. 295.

Figure 24. Third-generation scanner.



Reproduced, by permission, from Bushong, S. C.: **Radiologic Science for Technologists**, 5th ed., 1993, Mosby Year Book, Inc., St. Louis, Missouri, pg. page 413.

Figure 25. Fourth-generation scanner.

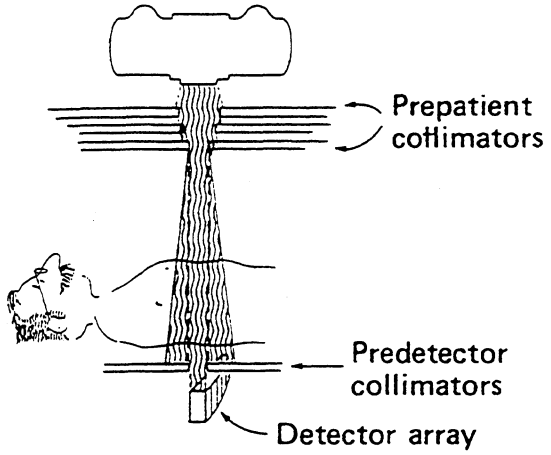


Reproduced, by permission, from Thomas S. Curry III, M.D., et al: **Christiansen's Introduction to the Physics of Diagnostic Radiology**, 4th ed., Lea & Febiger, Philadelphia, 1990, pg. 296.

Figure 26. Fourth-generation scanner.

B. COLLIMATION.

As in other areas of radiographic imaging, CT requires collimation to reduce patient dose and enhance image quality by reducing scatter. CT scanners typically have two collimators, a prepatient collimator and a predetector collimator (see Figure 27, page 39). The prepatient collimator is mounted on the X-ray tube housing or is adjacent to it. The majority of unnecessary radiation dose from CT examinations occur when the prepatient collimator is improperly adjusted.



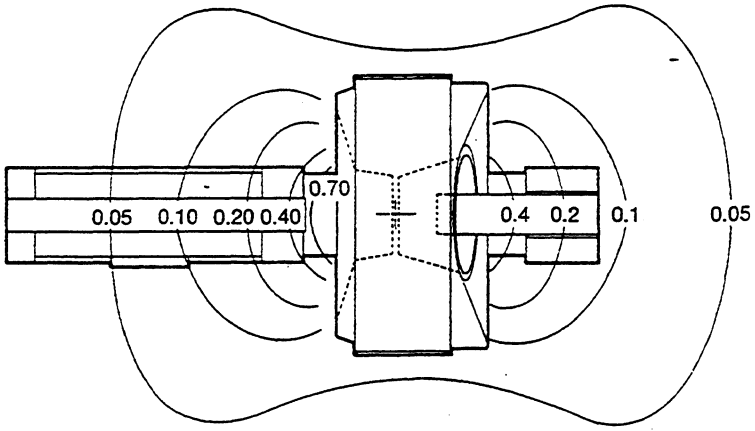
Reproduced, by permission, from Bushong, S. C.: **Radiologic Science for Technologists**, 5th ed., 1993, Mosby Year Book, Inc., St. Louis, Missouri, pg. page 417.

Figure 27. CT scanners incorporate both prepatient and predetector collimators.

C. RADIATION PROTECTION.

Patient skin dose for CT examinations is usually on the order of one to several rads. This compares to planar radiography which usually is in the millirad range when fluoroscopy and special procedures are not involved in the examination. As with any other radiographic examinations, dose is dependent on a variety of factors including the area being scanned, exposure factors, and in the case of CT, the sensitivity of the X-ray beam detectors. The more sensitive the detectors in the CT scanner, the smaller the radiation exposure necessary to produce a diagnostic image of acceptable quality.

Operator exposures from CT examinations are very low. The CT beam is well collimated with scatter radiation confined to the examination room (see Figures 28, and 29, page 40). As with other radiographic examinations, if the operator is required to remain in the room during patient scanning, protective apparel and personnel dosimeters must be worn.



Reproduced, by permission, from Bushong, S. C.: **Radiologic Science for Technologists**, 5th ed., 1993, Mosby Year Book, Inc., St. Louis, Missouri, pg. page 650.

Figure 28.

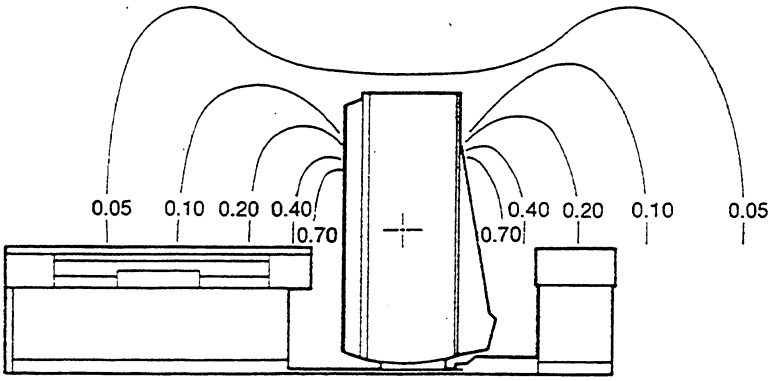


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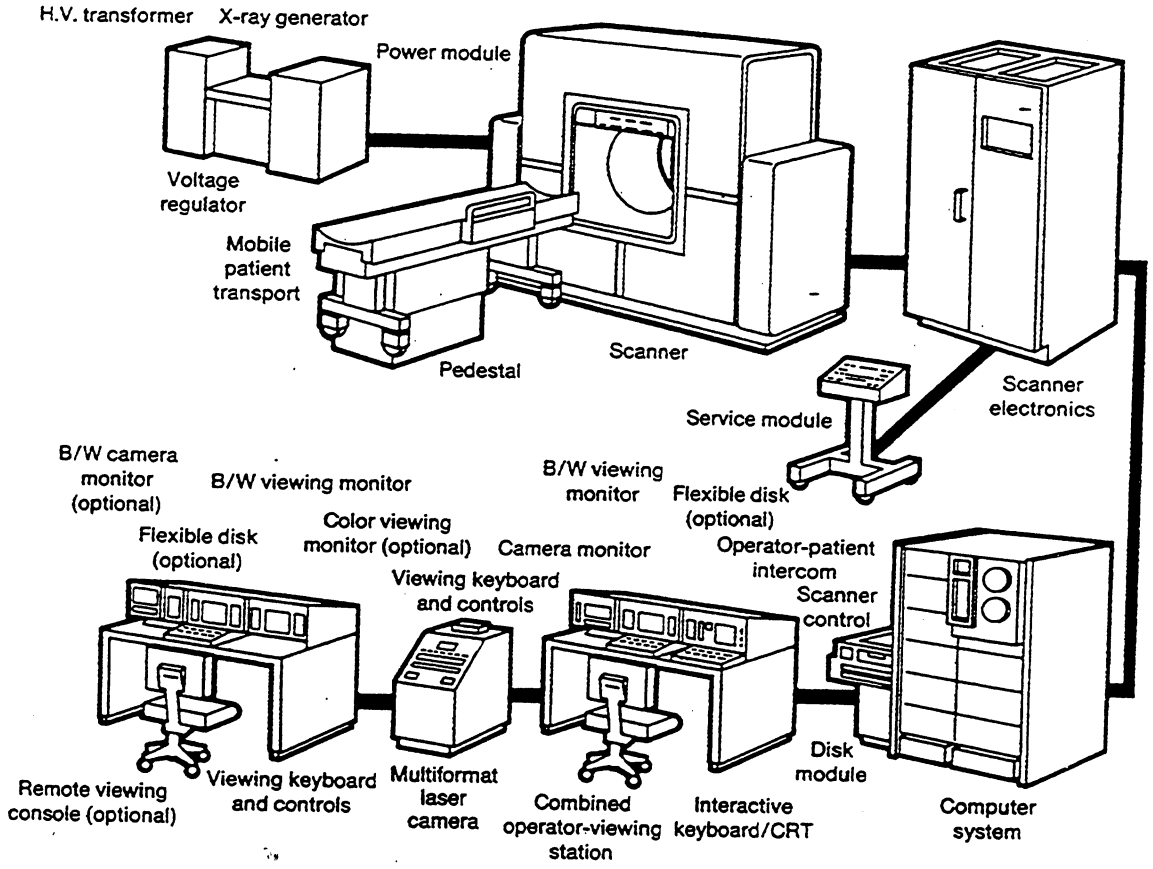
Figure 29.

Isoexposure profiles (in millirads/scan) in the vertical plane for a typical CT operation. (Courtesy General Electric Medical Systems.)



Components of a complete CT scanner system.

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CHAPTER VI

MOBILE RADIOGRAPHIC EQUIPMENT

Where applicable, mobile radiographic equipment must meet the same requirements as stationary units [section 30309 (a) (1)]. There are certain regulatory provisions that are specific to mobile radiographic equipment. These are:

A. STRUCTURAL PROVISIONS.

1. When mobile equipment is to be used routinely in one location, shielding must be provided as for a fixed radiographic installation.

2. When mobile equipment is routinely used in operating rooms, appropriate structural shielding must be provided for these rooms.

B. EQUIPMENT PROVISIONS.

1. The exposure switch shall be of the dead-man type and be so arranged that the operator can stand at least 6 feet away from the patient and well away from the useful beam [section 30309 (a) (2)].

2. The source-to-skin distance must not be less than 12 inches [section 30309 (b) (2)].

3. Personnel monitoring is required for all persons operating mobile X-ray equipment [section 30309 (b) (3)].

C. GONAD SHIELDING AND PROTECTIVE APRON.

Gonad shields shall be carried with the mobile X-ray unit and used on patients who have not passed reproductive age for those procedures in which gonads are in the direct beam, except where this would interfere with the diagnostic procedure (see also pages 12 - 15).

Protective aprons shall be available and used when indicated.

D. OPERATION OF MOBILE X-RAY UNIT.

X-ray personnel may not make an exposure unless:

- All individuals who must remain in the room are well away from the primary X-ray beam and the patient
- All individuals in the room, except the patient, wear protective aprons
- All individuals, except the patient, wear a personnel monitoring device

CHAPTER VII

HEALTH EFFECTS OF LOW-LEVEL X-RAY RADIATION DOSE

It has been established beyond any doubt that exposure to ionizing radiation can result in damage to the individual irradiated and produce undesirable effects in future generations. These two broad classes of biological impact are generally referred to as **somatic** and **genetic** effects, respectively.

The proper significance of various radiation dose expressions is dependent upon which of these two classes of biological effects is involved and the extent of the radiation dose received.

A. SOMATIC DOSE INDICATORS.

Concern about the effect of the irradiation an individual receives can be expressed in those doses that may induce somatic change such as:

- o Injuries to the superficial tissue
- o Induction of cancer
- o Other deleterious effects such as cataract formation, impaired fertility, and life-span shortening
- o Injuries to the developing fetus/embryo

Most somatic dose indicators are based on measurements of the dose at specific locations, points, or small volumes. The bone marrow, skin, and the thyroid are examples of anatomical points and locations that have been used for such measurements. However, the measurement of a dose at a single anatomical point cannot express the total somatic effect which may result from exposures due to diagnostic radiology examinations. In diagnostic radiology, the doses are not uniformly distributed throughout the body for several reasons:

1. The primary X-ray beam is normally restricted to the anatomical area of interest and does not uniformly expose the whole body. Thus, measurement of the radiation dose received by the testes during a chest examination (internal scatter) provides no indication of the dose received by the bone marrow. In other words, examinations which do not include the measured point in the primary X-ray beam provide incomplete information as to the full biological effect of the radiological procedure.

2. Shielding or protection may be used to cover particular parts of the patient during an examination. For example, shielding of the testes might be used during a pelvis examination; thus, measurement of the dose received by the testes would not be indicative of the dose received by surrounding tissue which is not shielded or vice versa.

3. Some natural shielding of particular organs is provided by overlying tissue. For example, measurement of the skin dose in the primary X-ray beam during an abdominal examination produces a higher value than measurement of the ovarian dose.

Nevertheless, the somatic dose indicators are useful in their own right as long as their limitations are understood and are indicative of the major effect.

1. Bone Marrow.

Irradiation of the bone marrow will result in a hematological depression. Lymphocytes will be depressed most severely. Evaluation of data regarding the irradiation of the bone marrow suggests that a strong correlation exists between the incidence of leukemia and the mean radiation dose received by the active bone marrow. Further, the bone marrow dose is a reasonable indicator of doses to other internal organs which are sensitive to cancer induction (lung, GI tract). Considering the mortality rates associated with these cancers, bone marrow dose may be singled out as a reasonable indicator of somatic effects. (**High bone marrow dose examinations are: lumbar spine, retrograde urography, abdominal angiography, chest tomography.**)

2. Thyroid and Skin.

The measurement of radiation doses to other organs of the body such as the skin and thyroid may be useful to determine the probability of certain effects occurring. A skin dose is often determined for a procedure since it may indicate the level of doses received by organs near the point of interest. For example, measurement of the dose to the skin of the anterior chest is a reasonable indicator of the breast dose or measurement of a skin dose obtained from a cervical spine examination may be indicative of the absorbed thyroid dose. Appendix No. 9, page 84, lists California entrance skin radiation dose averages for many common X-ray examinations.

B. GENETIC DOSE INDICATORS.

The genetic dose refers to effects exhibited in future offspring of persons who have been irradiated. It does not refer to the individual or embryo/fetus which directly received the radiation exposure. These effects which are manifested in subsequent generations are referred to as **inherited or genetic** effects. The effects in individuals whose gonads have been irradiated are slightly different for the male and female. Although the sperm precursors, the spermatogonia, are among the most radiosensitive cells in the body, the mature spermatozoa are quite radioresistant. The BEIR Report states the following regarding exposure of the testes:

> "Spermatogonia are drastically depleted by small amounts of radiation; i.e., a dose of 50 rem delivered in a single brief exposure may result in cessation of sperm formation. Fertility is not impaired, however, until the preexisting sperm cells and those found from the maturation of surviving spermatocytes and spermatids are eliminated from the genital tract, which takes several weeks. The sterility ensuing after such a dose may be expected to be only temporary, since enough spermatogonia survive to restore spermatogenesis through eventual regeneration of the seminiferous epithelium."

Regarding the female, the BEIR Report has the following to say: The female possesses:

> "...its entire supply of germ cells, or oocytes, early in life and lacks the ability to replace them as they are lost subsequently. Hence, since oocytes are relatively radiosensitive, irradiation causes a lasting reduction in the reproductive potential of the affected ovary, varying in severity with species, age, and other factors."

It is important to note that acute doses on the order of 300 rads to the female ovaries will produce temporary sterility while an acute dose of only 30 rads to the testes results in temporary sterility in men. These are not doses which would be encountered in routine diagnostic radiographic examinations (see Appendix 9, page 84). If one is concerned about reduced fertility, measurement of doses to the testes and ovaries is needed.

As one would expect, examinations that expose the gonads to primary X-ray beam irradiation produce the highest gonad exposures (barium enema examination, IVP, lumbar spine, hips and upper femur). However, even the high dose radiographic examinations result in doses to the gonads which are below those that will reduce or impair fertility.

Review of worldwide data on a gonad dose from various X-ray examinations reveals that doses vary by many orders of magnitude for the same examination from one facility to another. The data show, for example, that the testicular dose from a lumbar spine examination can vary by a factor of 100. The same variation may be noted in the ovarian dose resulting from hysterosalpingography. These wide ranges can be in part accounted for by variation in the selection of exposure factors, variation in the restriction of the primary X-ray beam, use of improper X-ray beam filtration, and failure to use gonad shields during the examination.

When the reproductive calls are irradiated, changes may be produced in the genes or in the chromosomes of these cells and subsequently be transmitted to the descendants of the irradiated individual. The effects that are manifested in subsequent generations are referred to as inherited or genetic effects.

C. GENETICALLY SIGNIFICANT DOSE (GSD).

When the reproductive cells are irradiated, changes may be produced in the genes or in the chromosomes of these cells and subsequently be transmitted to the descendants of the irradiated individual.

A statistic called the genetically significant dose (GSD) has been developed to estimate the magnitude of genetic effects caused by exposure of the population to radiation. The GSD is defined as the "gonad dose which, if received by every member of the population, would be expected to produce the same total genetic effect on the population as the sum of the individual doses that are actually received." It does not include the dose the population receives from background radiation.

The GSD factor is dependent upon three parameters:

- Future child expectancy
- X-ray examination rate
- Mean gonad dose per examination

It is assumed that future child expectancy is the same for all individuals of the same age–sex–class.

Since radiation can induce deleterious mutations which can be expressed in future generations, it can be deduced that the lower the GSD, the lower the number of mutations. This is why the concept of the GSD is currently receiving great emphasis as an important statistic. However, it should be kept in mind that the GSD is not a prediction or forecast of adverse effects on any individuals or their unborn children.

The total estimated Mean Annual Genetically Significant Dose to the U.S. population has been estimated for the year 1970 to be 20 millirads, a 20 percent increase over that of 1964. There is no reason to believe that the upward trend is not continuing. **It is of interest to note that the lumbar and lumbosacral examinations are the largest contributors to the GSD.** Contrast the fact that examinations of the thorax account for approximately half of all diagnostic radiographic examinations taken, but contribute only a few percent to the total GSD, with the fact that examinations of the abdominal region of the body account for approximately 25 percent of all radiography, but contribute over 70 percent of the GSD.

CHAPTER VIII

BIOLOGICAL EFFECTS AND SIGNIFICANCE OF RADIATION DOSE

The physical basis for the biological consequences of ionizing radiation exposure is the transfer of energy to the biological organism (deposition of energy in tissue). The energy transferred to matter from ionizing radiation produces **ionizations** of atoms (electrons removed from an atom) and molecules. The deposited energy also produces **excitations** (electron vacancies in shells) of atoms and molecules in the absorbing material.

Basically, radiation could:

- o Pass through the cell without producing any damage
- o Could kill the cell
- o Damage the cell but such damage could be repaired adequately
- o Can lead to permanent changes in the tissue which may result in demonstrable biological injury (see Appendix No. 3, page 73 - Stepwise Effects of Radiation Injury)

The specific mechanisms involved in radiobiological injury are not completely understood; however, nucleic acids are probably involved in the more serious effects. Small modifications of DNA structures can have widespread consequences for the cell because the structure of a DNA molecule constitutes the cell's operational "program." In addition, since DNA is replicated during mitosis, any mutation may be perpetuated in the cell's progeny. For example, a particular alteration could result in the synthesis of enzymes which differ from normal in time of production, spatial distribution, or configuration. Depending upon the relative importance of particular enzymes, their activity, and the frequency of their production, the effects upon the cell as a whole can range from insignificant metabolic alterations to severe interruption of normal function.

Biological effects of radiation are influenced by:

- o Dose rate to the tissue exposed
- o Total dose received by the tissue exposed
- o Type of cell irradiated

A. RADIOBIOLOGICAL INJURY.

The severity of radiobiological injury is also clearly dependent upon the specific location of the initial radiation interaction. For example, small alterations in the protein synthetic mechanism occurring in the cytoplasm of the cell might cause localized damage but would be unlikely to generate large-scale changes in cellular activity.

1. Cellular amplification.

Cellular damage at the point of the initial radiation interaction usually involves only a very small percentage of the total number of molecules in the cell. At this stage, therefore, any biological consequences of radiation-induced changes may be relatively insignificant. Subsequently, normal cellular metabolic processes may amplify this damage, causing the injury to develop from the molecular to the microscopic anatomical level, ultimately resulting in possible gross cellular malfunction.

2. Gross cellular effects of radiation - cellular, molecular and organic.

The phenomenon seen most frequently in growing tissue exposed to radiation is the cessation of cell division. This may be temporary or permanent, depending upon the magnitude of the absorbed dose of radiation.

Other factors observed are:

- o Chromosome breaks
- o Clumping of chromatin
- o Formation of giant cells or other abnormal mitoses
- o Increased granularity of cytoplasm
- o Nuclear disintegration
- o Changes in motility or cytoplasmic activity
- o Vacuolization
- o Altered protoplasmic viscosity
- o Changes in membrane permeability

3. Latent period.

Following the initial radiation exposure event, and before the first clinically detectable effects occur, there is a time lag referred to as the latent period. The biological effects of radiation are arbitrarily divided into short-term (sometimes called immediate or early effects of radiation) and long-term effects (sometimes called delayed or late effects of radiation) on the basis of the latent period. Those effects which appear in a matter of minutes, days, or weeks are called short-term effects and those effects which appear years, decades, and sometimes generations later are called long-term effects (see Appendix 3, page 73).

B. DETERMINANTS OF BIOLOGICAL EFFECTS.

1. The dose-effect curve.

For any biologically harmful agent it is useful to graph the dosage administered against the probability of effect. With radiation, an important question has been the nature and shape of the resulting graph or curve. Figure 31, below, is a typical sigmoid "threshold" curve. The point at which the curve intersects the abscissa is the threshold dose, that is, the dose below which there is no detectable effect.

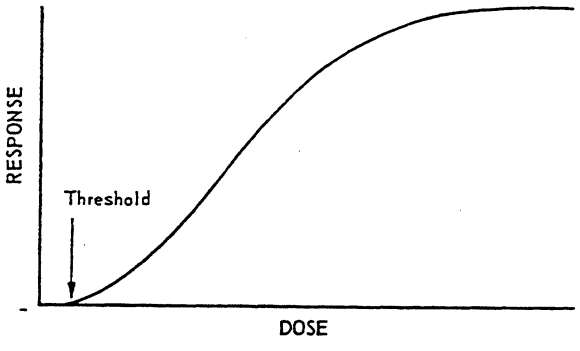


Figure 31.

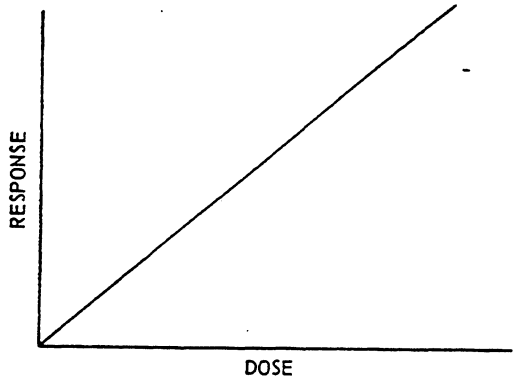


Figure 32.

Threshold, Nonlinear Dose-Effect Curve Nonthreshold, Linear Dose-Effect Curve

Figure 32, page 46, represents a linear, nonthreshold dose-effect relationship in which the curve intersects the abscissa at the origin. According to the nonthreshold hypothesis, any dose, no matter how small, is considered to involve some degree of effect. There is some evidence that the **genetic effects** of radiation constitute a nonthreshold phenomenon. One of the underlying assumptions in the establishment of radiation protection guides has been to take the conservative approach and consider that any radiation absorbed will exhibit a nonthreshold effect. Under this assumption, some degree of risk is presumed to be present when large populations are exposed to even very small amounts of radiation.

It is important to note that controversy surrounds radiation dose/effect curves and the presence or lack of a threshold. However, regulatory radiation guides are based on the nonthreshold dose-effect relationship.

2. Area exposed and shielding of radiosensitive organs and body parts.

The extent of the effect is measured by the total radiation received by the patient and primarily depends upon the total area exposed. Of equal importance is the nature of the organs in the body area exposed. Even partial shielding of the radiosensitive blood-forming organs such as spleen and bone marrow can mitigate the total effect, especially when X-raying children.

3. Variations in cell sensitivity.

There is wide variation among different types of cells in the amount of radiation required to produce radiation damage. For example, cells which are rapidly dividing, or have a potential for rapid division, are more sensitive than those which do not divide, and cells which are nondifferentiated (i.e., primitive or nonspecialized) are more sensitive than those which are highly specialized. The factors which generally influence the radiosensitivity of cells and tissues were recognized as early as 1906 by two French scientists. Their findings are expressed in the **law of Bergonié and Tribondeau**, which states:

> "The radiosensitivity of tissues depends on the number of undifferentiated cells which the tissue contains, the degree of mitotic activity in the tissue, and the length of time the cells of the tissue stay in active proliferation."

Radiation-induced mitotic delay in the life cycle of a cell is usually reversible.

Based on these factors, it follows that blood forming organs (spleen, and red bone marrow), gastrointestinal tissue, and the developing embryo/fetus (especially during the first trimester) will be more radiosensitive than tissues whose cells have a slower renewal rate.

Various kinds of cells may be grouped as follows, in order of **diminishing** sensitivity:

- Lymphocytes or white blood cells
- Erythrocytes or red blood cells, granulocytes
- Epithelial cells
- Endothelial cells
- Connective tissue cells
- Bone cells
- Muscle cells
- Nerve cells
- Brain cells

4. Short-term effects.

With each routine diagnostic X-ray examination there is a very small probability of an individual receiving an acute injurious effect. The dose range for diagnostic radiographic examinations usually varies from a few millirads (mrad) to a few rads.

Most of the data pertaining to the short-term effects of radiation comes from animal experimentation, but there are human data which confirm the extrapolation of the animal data to human populations. In general, at 25 rads or less ordinary laboratory or clinical methods will show no indications of injury.

5. Long-term effects.

Long-term effects of radiation exposure are those which may manifest themselves years after the original exposure. The latent period, then, is much longer than that associated with the **acute radiation syndrome**. Delayed radiation effects may result from previous acute, high-dose exposures or from chronic low-level exposure over a period of years or both.

From the standpoint of public health significance, the possibility of long-term effects on many people receiving low, chronic exposures is cause for greater concern than the short-term effects of a few individuals receiving a high dose. This is because of possible deleterious genetic and carcinogenic effects over an entire population.

With the exception of radiation induced cataracts which may be differentiated from other types of cataracts, there is no unique disease associated with the long-term effects of radiation; these effects manifest themselves in human populations as a statistical increase in the incidence of certain diseases or pathology.

Many epidemiological investigations on irradiated human beings have provided convincing evidence that ionizing radiation does indeed result in an increased risk of certain diseases long after the initial irradiation. This evidence supplements and corroborates that gained from past and present animal experimentation which demonstrates these same effects.

Among the long-term effects thus far observed are:

(1) Somatic damage, which may result in an increased incidence of cancer, embryological effects, cataracts, and life-span shortening.

(2) Genetic mutations, which may be expressed many generations after the original radiation damage.

6. Carcinogenic effects.

There is human evidence that radiation may contribute to the induction of various kinds of neoplastic disease. This evidence includes the following:

(1) Early radiologists and dentists manifested a significant increase in skin malignancies and leukemias as compared to physicians who did not use radiation.
(2) Radium dial painters, who ingested significant amounts of radioactive radium, have subsequently shown an increased incidence of bone malignancies.
(3) Uranium miners have shown an increased incidence of lung cancer.
(4) The Japanese survivors of Hiroshima and Nagasaki have an increased incidence of leukemia and other neoplasms.

The most frequently occurring radiation-induced cancers include, in **descending** order of susceptibility:

- o Female breast
- o Thyroid gland (especially in women and young children)
- o Hemopoetic tissue
- o Lungs
- o Gastrointestinal tract
- o Bones

7. Embryological effects.

Considering the fact that immature, undifferentiated, and rapidly dividing cells are highly sensitive to radiation, it is not surprising that embryonic and fetal tissues are readily damaged by even relatively low doses of radiation. Absorbed doses of about 50 rads to the fetus could result in a spontaneous abortion. It has been shown in animal experiments that deleterious effects may be produced with doses of as little as ten rads delivered to the embryo. There is no reason to believe that the human embryo is not equally susceptible to radiation damage.

The specific type of fetal radiation damage is related to the dose and to the stage of pregnancy during which the irradiation takes place. In terms of embryonic death, the earliest stages of pregnancy, perhaps the first few weeks in human beings, are the most radiosensitive.

From the standpoint of practical radiation protection, this early sensitivity is of great significance, because pregnancy may well be unsuspected. Appendix No. 4, page 74, addresses special considerations concerning scheduling women of childbearing capability for X-ray examinations. During the second through sixth weeks of human gestation (organogenesis), the production of morphological defects in the newborn is a major consideration.

During later stages of pregnancy, fetal tissue is more resistant to damage by radiation. However, functional damage, particularly those involving the central nervous system, may result from such late exposure. They can involve subtle alterations in such phenomena as learning patterns and development, and may have a considerable latent period before they manifest themselves.

8. Cataractogenic effects.

The required dose for formation of cataracts in humans is probably on the order of several hundred rads of acute dose for X-rays in the diagnostic energy range. The fibers which comprise the lens of the eye are specialized to transmit light. Damage to these, and particularly to the developing immature cells which give rise to them, can result in cataracts.

9. Life-span shortening.

In a number of animal experiments, radiation has demonstrated a life-span shortening effect. The mechanisms involved in radiation life-span shortening are uncertain, however, irradiated animals appear to die from the same diseases as the nonirradiated controls but at an earlier age. How much of the total effect is due to premature aging and how much to an increased incidence of radiation-induced damage is still unresolved and quite controversial.

10. Genetic effects.

The precursor cells of mature gametes or the mature gametes themselves are susceptible to nuclear damage (genetic mutations) from external influences such as radiation. When this occurs in those gametes which subsequently are utilized in conception, the altered genetic information is reproduced and passed on to all of the cells of the offspring.

Most geneticists agree that the greatest preponderance of genetic mutations are harmful. By virtue of their damaging effects, they can be gradually eliminated from the population through natural selection. The more severe the defect produced by a given mutation, the more rapidly it will be eliminated, while the reverse is true for mildly damaging mutations which may require a great many generations before they disappear.

Animal experimentation remains our chief source of information concerning the genetic effects of radiation. As a result of extensive experimentation, certain generalizations may be made:

(1) There is no indication of a threshold dose for the genetic effects of radiation, i.e., no dose below which genetic damage does not occur.

(2) The degree of mutational damage which results from radiation exposure seems to be dose-rate dependent (i.e., a given dose is less effective in producing damage if it is protracted or fractionated over a long period of time).

Radiation and other mutagenic factors have always been present on earth. It is reasonable to expect that all mutations have been expressed in the past so that man-made radiation would only add to the natural incidence of previously expressed mutations rather than create new ones. In general, mutations tend to be deleterious, that is, can produce undesirable effects in future generations. **Therefore, the goal is clear -- keep the radiation exposure of the gonads to a minimum.**

CHAPTER IX

PERSONNEL RADIATION PROTECTION

A. ALARA

ALARA is an acronym for "As Low As Reasonably Achievable." ALARA means that any radiation dose (including occupational dose equivalent) be kept as low as reasonably achievable. It is assumed that there is no minimum threshold of radiation dose necessary to achieve a biological effect. Even the lowest radiation dose is assumed to result in some effect, though this effect may be too slight to measure. This concept is the basis for the radiation protection goal of reducing exposure whenever possible in order to reduce any unnecessary risk. It stresses that all radiation doses (X-ray operator, staff and patient) be kept as far below legal limits as possible.

B. Basis for Radiation Protection Requirements.

The radiation protection objective is to **prevent** detrimental non-stochastic or deterministic effects and to limit the probability of stochastic effects to a level deemed acceptable.

Stochastic effects mean the probability of an effect occurring, rather than its severity. It is regarded as a function of radiation dose without a threshold. Examples: some somatic effects such as carcinogenesis, or genetic effects.

Non-stochastic effects mean those effects for which the severity of an effect varies with radiation dose, and for which a threshold may occur. Examples: cataracts, non-malignant skin damage, bone marrow cell depletion.

In order to **prevent** detrimental non-stochastic or deterministic effects, the supervisor must set dose equivalent limits to sufficiently low values so that no threshold will be reached.

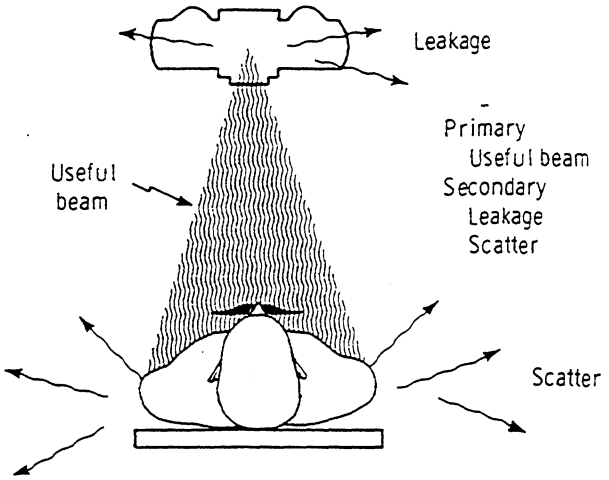
In order to **limit** the probability of stochastic effects, the supervisor must abide by the following:

1. Keep all justifiable radiation doses ALARA (as low as is reasonably achievable), economic and social factors taken into account, and
2. Ascertain that no occupationally exposed individual receives more than 5 rems whole body dose equivalent in one year.

C. OPERATOR EXPOSURE.

The chief danger to the operator during radiographic procedures is possible exposure to the scattered radiation coming primarily from the patient and, to a lesser degree, other scattering media such as the collimator, X-ray tabletop, bucky tray, or X-radiation coming from the X-ray tube housing [leakage radiation - section 30306 (h)]. The irradiation can occur only when the radiographic unit is activated (during exposure only). In order to avoid being exposed to the unwanted, so-called stray radiation [section 30306 (n) - stray radiation includes leakage and scatter radiation - see Figure 33, page 52], all radiographic operators must stand in a control station behind a protective barrier during the exposure [section 30308 (b) (5)].

If the operator stands behind the protective barrier, as required by law, a typical exposure reduction to a **primary X-ray beam** exposure is 99.87 percent. Thus, for example, for a 100 kVp primary X-ray beam, the transmission through the usual operator shield of 1/16 inch (1.58 mm) of lead is 0.13 percent. Therefore, the reduction is 100 percent minus 0.13 percent equals 99.87 percent. (For a portable shield which may allow scattered radiation to pass around its edges, the total radiation dose reduction would be approximately 99 percent.)



Reproduced, by permission, from Bushong, S. C.: **Radiologic Science for Technologists**, 5th ed., 1993, Mosby Year Book, Inc., St. Louis, Missouri, pg. 632.

Figure 33. Three types of radiation - the useful X-ray beam, leakage radiation, and scatter radiation.

The operator's station at the control panel must be behind a protective barrier, either in a separate room, in a protective booth, or behind a shield which will intercept the useful X-ray beam and any radiation which has been scattered once. The best protection for the operator from scattered radiation is obtained by remaining behind a lead protective barrier during the time of X-ray exposure.

A patient-viewing window with radiation attenuation equal to that required by the adjacent barrier must be provided. If a patient-viewing window cannot be installed, a mirror system must be provided. Additionally, provisions must be made for the operator to communicate with the patient from a shielded position at the control panel.

The dead-man type exposure switch, which terminates exposure when pressure is released, must be so arranged on the control panel that it cannot be conveniently operated outside a shielded area.

D. PROTECTIVE APPAREL AND ACCESSORIES.

1. Protective aprons.

If the operator is required to remain in the radiographic room during the exposure, he/she must:

- Stand as far as practicable from the scattered radiation source (patient)
- Wear appropriate protective apparel [section 30308 (b) (2)]
- Use personnel monitoring devices (section 30276)

If the operator is wearing protective clothing, substantial radiation dose reduction from **scattered** radiation can be achieved. A typical radiation dose reduction is 97 percent. For example: If the minimum lead equivalence of protective clothing is 0.25 mm of lead, the transmitted exposure would be lessened by approximately 97 percent. On the other hand, if the minimum lead equivalence of the protective clothing is 0.5 mm of lead, the transmitted exposure reduction to scattered radiation is 99.9 percent. The normal thicknesses for protective apparel are 0.25 mm, 0.5 mm and 1.0 mm of lead equivalent. However, there are also lead aprons with 0.35 mm and 0.75 mm lead equivalent available commercially.

Hangers for protective aprons should always be used for storage. These help in at least two ways:

(1) They prevent excessive local strain on the apron or coat shoulders and thus help to prevent cracking of the protective lead material.

(2) They make putting the apron on much easier.

2. Thyroid shields.

Thyroid shields of 0.25 mm and 0.5 mm lead equivalent are available to protect the thyroid from radiation. These devices are generally only utilized when the wearer is in close proximity to the patient during fluoroscopy, but may have limited applications during special situations such as patient holding in radiography.

3. Protective gloves.

Protective gloves of 0.25 mm and 0.5 mm lead equivalent are available. These devices along with other protective apparel have special application when patient holding is required.

4. Lead glass protective goggles and glasses.

Lead glass protective goggles and glasses are available from commercial companies to protect the lens of the eyes from radiation. As with thyroid shields, these devices are generally only utilized when the wearer is in close proximity to the patient during fluoroscopy, but may have limited applications during special situations in radiography such as patient holding.

E. PATIENT HOLDING IN EMERGENCY ONLY.

In lieu of holding patients during radiographic examinations, mechanical holding devices, positioning aids, and similar accessories should be employed whenever possible.

When patient holding is unavoidable (**in emergency only**), it is important to keep scattered radiation intensities in mind. The scatter from the patient contributes significantly to the radiation dose of the person holding the patient. The maximum exposure rate can be found at the side of the table. It is of concern to note that most of the reported overexposures of X-ray personnel have occurred during patient holding. Although most occupational exposure comes from scattered radiation, in some instances X-ray personnel have been exposed unnecessarily to the primary X-ray beam.

A permanent record should be kept of individuals who have been required to hold patients and of the radiation dose they have received. **Students shall not be permitted to hold patients.**

The following guidelines must be followed by individuals who are occupationally exposed to radiation. An occupationally exposed person:

(1) May hold a patient **only if there is an emergency**.

(2) May **not be used routinely** to hold patients.

No individual may be permitted to hold patients repeatedly.

If any person must hold a patient, that person:

(1) Must be protected with appropriate shielding devices such as protective apron and protective gloves [section 30308 (b) (1)].

(2) Must be so positioned that no part of his/her body will be struck by the useful X-ray beam [section 30308 (b) (1)].

(3) Must be wearing an appropriate personnel monitoring device such as pocket ionization chamber or audible warning device **outside** the apron or on the collar outside the apron.

(4) Should be a non-occupationally exposed person, that is, family member of the patient, preferably father.

E. EXPOSING AN INDIVIDUAL TO THE USEFUL X-RAY BEAM SOLELY FOR DEMONSTRATION.

Deliberate exposure of an individual to the useful X-ray beam for training or demonstration purposes is not permitted unless there is also a medical indication for the exposure and the X-ray examination was **prescribed by a physician** [section 30305 (b)(4)].

CHAPTER X

PERSONNEL MONITORING

Because human senses do not detect ionizing radiation, other means for determining radiation exposure must be provided. As a result, radiation monitoring equipment [section 30100 (l)] have been designed to measure the radiation level or accumulated exposure to the individual by taking advantage of the ionization of matter by radiation. The monitoring devices do not provide any protective or shielding ability from radiation.

A. PERSONNEL MONITORING EQUIPMENT.

Personnel monitoring equipment means devices designed to be worn or carried by an individual for the purpose of measuring the dose equivalent received by that individual. Personnel monitoring equipment (film badges, pocket chambers, pocket dosimeters, film rings, thermoluninescent badges) must be worn **only when on the job** and the equipment (device) should be stored in a safe place at the X-ray facility.

Ideally, personnel monitoring devices should fulfill at least four criteria:

(1) Record the exposure (quantity) to ionizing radiation that has occurred.

(2) Measure the accumulated exposure (quantity) over a specified period of time.

(3) Provide some indication of the type and energy (or quality) of the incident radiation and the rate at which it was received (acute or chronic).

(4) Provide a legally acceptable record of personnel exposure.

A personnel monitoring device only records the radiation exposure to the small body area in the vicinity of the device. If only one personnel monitoring device is worn, a notation of the position at which it was worn should be made. The real exposure the individual receives may be many times the amount recorded if significantly more radiation is received at a location remote from the monitoring device.

Any personnel monitoring device reading (unless specifically identified otherwise) is considered to be a whole-body radiation dose.

Acceptable personnel monitoring devices are:

- Film badge
- Thermoluminescent dosimeter (TLD)

For other special purposes the following personnel monitoring devices may be worn **in addition to** the above:

- Pocket chamber or dosimeter
- Audible warning device

It is important to remember that the pocket chamber or dosimeter, while providing an immediate indication of the exposure received, does not provide a permanent record and, therefore, is not acceptable for legal monitoring purposes. Also, the audible warning devices give only an indication that radiation is present and by the frequency or pitch of sound indicates only the intensity of radiation. Each of these devices may only be used **in addition** to a film badge or TLD.

1. Film badge.

Film badges for personnel dosimetry (monitoring) utilize a comparison of film which has been exposed to a known (measured) amount of radiation at the supplier origin to a film which was worn by an individual as a personnel monitoring device and exposed to an unknown amount of radiation.

The film badge has two essential components:

(1) The film holder with a variety of filters.

(2) The packaged film.

The film holder is usually made of lightweight, low atomic number plastic material and is quite rugged. The holder has various filters embedded in it which act as filters of low energy X- and gamma rays, as well as for beta particles. The attenuation of radiation that occurs from the various filters results in different film densities when the film is developed. Measurements using this information permit calculation of personnel exposure regardless of energy or type of radiation. Comparison of these densities also permits estimates of radiation energy and type. Under certain conditions, the actual shadow cast by the filters on the developed film allows some estimate of the direction from which the radiation was incident upon the film and may indicate whether the film was exposed once or more than once.

Prepackaged film is the recording medium for the radiation exposure. Films that are presently used for film badge dosimetry purposes are sensitive to exposure equivalent to doses as low as 10 millirad and up to as high as 700 rads. (The dose in rads can then be converted to rems by using an appropriate quality factor which is based on the type of radiation detected. One rem of X-rays is approximately equivalent to one rad.)

2. Thermoluminescent dosimeter (TLD).

The most common material used in the thermoluminescent dosimeters is lithium fluoride in the form of solid chips. Some TLD materials are hygroscopic and light sensitive, and must therefore be placed in hermetically sealed, light-tight holders.

Thermoluminescent dosimeters function on the principle that as ionizing radiation interacts with lithium fluoride crystals, some electrons of the crystal are raised to higher energy states of excitation, in which they become trapped. Later, when the crystals are heated in a special measuring device, these trapped electrons return to their normal energy levels and, in the process, emit light. The amount of light emitted is proportional to the amount of radiation to which the crystal was exposed. The average accuracy of TLDs is about ± 9%. This far exceeds the average accuracy of film badges, which may be as poor as ± 25%.

However, TLDs are generally more costly than film badges. A major disadvantage of utilizing TLDs is that once the TLD exposure has been read, it cannot be read again (the exposure information is lost). Thus, it does not provide a truly permanent record of exposure.

3. Pocket ionization chamber.

The pocket ionization chamber is a small pencil-sized instrument that discharges a capacitor by ionization of air within the chamber when in the presence of ionizing radiation. The rate of discharge depends primarily on the intensity of the incident radiation.

Two types of pocket ionization chambers are commonly used for personnel monitoring, the self-reading type and one in which the reading is accomplished only with a special device. Both work on the same principle. There are certain basic and important **disadvantages** in using pocket ionization chambers as personnel monitoring devices. These are:

- o No permanent record
- o Must be periodically calibrated
- o Sensitive to mechanical shock
- o Subjective evaluation of reading by wearer
- o Limited dose range
- o Possible loss of information in the event of exposure over its maximum range

For these reasons, pocket ionization chambers are used **in addition to** (not as a substitution for) a film badge or TLD badge, especially when an immediate reading is desired or needed.

4. Audible warning device.

The drawback of film and TLD badges is that exposure results are available only after several weeks have passed, so that it is usually very difficult to pinpoint the cause of any overexposure or determine the time when it occurred. When an immediate warning is needed to indicate the presence of radiation, an audible type of exposure measuring device may be indicated.

The most practical audible warning device is the dose-rate meter, usually a Geiger-Mueller tube, which gives an audible signal as well as a visual digital display when the wearer is in the presence of radiation. This small device is encased in a rugged plastic or aluminum case which can be worn by a clip attached to the garment or belt or placed in a pocket. Sometimes it is advisable to wear this type of device **in addition** to a film or TLD badge during certain special procedures such as vascular studies or cardiac catheterization, in order to make sure that one does not remain in an intense radiation field for an unnecessary period of time.

5. Location for a personnel monitoring device.

It is important to remember that, unless specifically proven otherwise, any personnel monitoring device reading is considered to be a whole-body dose. Therefore, sometimes it may be advisable to wear two or more personnel monitoring devices (as in the case of pregnant radiation workers or during performance of special examinations).

Many X-ray personnel wear their personnel monitoring device (usually film or TLD badge) in front at the waist or chest level, because it is convenient to clip the badge over a belt or a pocket. However, when wearing a lead apron, the personnel monitoring device should always be positioned on the collar above the protective apron or on the top of the protective apron itself. If the exposure **under the apron must be determined**, as is advisable from time to time, then a second personnel monitoring device should be used.

In some clinical or other situations, it may be advisable to wear more than one type of personnel monitoring device. For example: (1) monitoring of the abdomen during pregnancy could use the self-reading type to obtain day-to-day indication of the accumulated exposure, or (2) monitoring extremities during some special procedure work in which the operator's hands may be in close proximity to the useful X-ray beam (dosimeters attached to finger rings are available for this purpose).

B. OCCUPATIONAL EXPOSURE.

1. Definitions.

"Whole-body dose" for the purposes of external exposure means exposure to **any** of the following:

- o Head
- o Trunk (including male gonads)
- o Arms above the elbow
- o Legs above the knee

2. Maximum permissible dose equivalent.

The primary objective in establishing maximum permissible dose equivalent (MPD) values for occupational exposure is to keep the radiation dose of occupationally exposed individuals well below a level at which adverse effects are likely to be observed during the lifetime of the radiation worker. While the risk of individuals exposed is considered small, it is worth remembering that risk increases gradually with the dose received. It is essential to keep radiation exposure to occupationally exposed persons as low as reasonably achievable (ALARA). For this reason, 10 CFR 20, section 20.1201 established the following **annual** occupational dose equivalent limits:

- o Whole body (total effective dose equivalent) - 5 rem or 0.05 Sv
- o Skin and extremities (shallow-dose equivalent) - 50 rem or 0.5 Sv
- o Lens of the eye (eye dose equivalent) - 15 rem or 0.15 Sv

Thus, it is the essential aim of radiation safety to prevent injury from ionizing radiation. The Regulations establish four types of maximum permissible dose equivalent:

(1) Occupational dose equivalent limits for adults (persons **over 18** years of age).

(2) Occupational dose equivalent limits for persons **under** 18 years of age (may receive 10 percent of the adult occupational dose limits).

(3) Dose equivalent limits for general population.

(4) Radiation dose to an embryo/fetus (prenatal radiation exposure - see Appendix No. 5, page 75).

Occupational dose is defined as the dose received by any individual in the course of employment.

Exception: Radiation dose received for the operator's own personal medical or dental diagnosis or medical therapy is not considered to be occupational exposure. If the radiologic technologist is a patient, then he/she must remove the personnel monitoring device before being exposed and place it behind a protective barrier.

3. Radiation dose limits for individual members of the public.

Each supervisor shall conduct X-ray operations so that no individual member of the public will receive more radiation dose in unrestricted area as indicated:

- o 0.1 rems (1 mSv) in a year, or
- o 0.002 rem or 2 millirems in any one hour

4. Frequency of exposure recording.

The personnel monitoring devices are worn in order to ensure that the maximum permissible dose equivalent or occupational dose equivalent limits have not been violated. The California Radiation Control Regulations do not specify the minimum or maximum monitoring time period. **Usually (and advisably) film badges or TLD badges are changed once every month.**

5. Overexposure of a personnel monitoring device.

Any reading indicating overexposure of a film badge or other type of dosimeter assigned to an individual is considered to be presumptive evidence of exposure to the individual and must be reported to the Radiologic Health Branch.

C. SUPERVISORY RESPONSIBILITIES.

There are two broad provisions which deserve emphasis:

1. Each supervisor must take all precautions necessary to provide reasonably adequate protection to the life, health, and safety of all individuals subject to exposure to radiation.

2. Each supervisor is responsible for radiation protection and safety in his/her X-ray department, including use of properly maintained and registered X-ray equipment, the operator's performance, the use of State authorized operators only, and quality and technical aspects of all X-ray examinations and procedures [section 11485 (g) of the Health and Safety Code] [old section 25661 (h) of the Health and Safety Code].

1. Monitoring requirements.

The question of who must be monitored and under what conditions persons must be monitored confronts every X-ray supervisor whose employees run a risk of exposure to radiation. As is often the case with regulations, there are many implied provisions. To a very great extent, this is true with personnel monitoring requirements. Radiologic Health Branch thinks that you should ask yourself: "Would you, as a supervisor want the responsibility of risking any person's safety by not monitoring that person?"

Those who are not convinced that a realistic and comprehensive monitoring of personnel is advisable should refer to the U.S Department of Health, Education, and Welfare publication (DMRE 69-3) entitled "Medical Radiation Information for Litigation."

In addition, there are two other classifications of personnel who must be monitored regardless of the exposure they are likely to receive:

1. Persons who enter a high radiation area.

2. Persons who operate mobile X-ray equipment [section 30309 (b) (3)].

"High radiation area" means any area, accessible to individuals, in which there exists radiation levels that could result in an individual receiving a dose equivalent in excess of 0.1 rem (1 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

"Radiation area" means an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.05 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

"Exposure" means being exposed to ionizing radiation or to radioactive material.

2. Personnel monitoring services.

If personnel monitoring is not performed in-house, it is recommended to utilize a personnel monitoring service vendor that is certified by the National Institute of Standards Technology (NIST) through the National Voluntary Laboratory Association Program (NVLAP) and/or certified by the National Sanitation Foundation Testing Laboratory as having met NSF Standard No. 16. Many of these vendors also provide other services such as TLD, area monitoring, computer interaction capability and a wide range of monitors for detection of various types of radiation.

A list of commercial personnel services vendors is available upon request from the Radiologic Health Branch (see address on page 69).

CHAPTER XI

SUPERVISION AND USE OF X-RAYS ON HUMAN BEINGS

California laws and regulations govern the use, supervision and operation of X-ray equipment. In addition, the provisions noted in this chapter apply specifically to stationary radiographic X-ray units including those located in mobile X-ray vans.

An X-ray Supervisor and Operator must be familiar with the following:

A. General provisions.

B. Specific supervisory responsibilities.

C. Technologist restrictions.

D. Technologist/technician performance requirements.

G. The display of documents.

H. Record keeping requirements.

I. Incident notification requirements.

J. Training and information to the X-ray personnel.

K. Responsibilities regarding X-ray equipment.

L. Communication with Radiologic Health Branch.

E. Compliance with regulatory provisions.

H. Enforcement authority and disciplinary action.

A. GENERAL PROVISIONS.

1. Licentiates of the healing arts (M.D.'s, D.O.'s, D.C.'s, D.P.M.'s) must hold one of the following documents issued by the California Department of Health Services, Radiologic Health Branch in order to use or to supervise the use of X-rays on human beings:

   a. Radiography Supervisor and Operator permit.
   b. Radiology Supervisor and Operator certificate.

2. The scope of use and supervision of use of X-rays on human beings of documents noted in 1. a. and b. above is limited to:

   a. Professional licenses issued by the California licensing boards.
   b. The technical education, expertise, and competency of holder of a certificate or a permit.

3. **Supervisors are required to post a copy of their certificates or permits at every facility (including mobile vans) where they supervise diagnostic radiologic technologists or limited permit X-ray technicians.**

4. Supervisors must be readily available by telephone or in person for consultation with diagnostic radiologic technologists or limited permit X-ray technicians who under their supervision perform radiographic procedures.

B. SPECIFIC SUPERVISORY RESPONSIBILITIES.

Supervisors are responsible for all of the following:

1. Establishing policies and procedures that will ensure the obtaining of diagnostic quality radiographs with the lowest acceptable exposure to the patient, X-ray personnel, and the general public.

2. Verifying that X-ray personnel possess the appropriate document(s) issued by the California Department of Health Services, Radiologic Health Branch, as follows:

   a. Radiologic technologists possess valid and current diagnostic radiologic technology certificates.

   b. Limited permit X-ray technicians possess valid and current permits for the procedures they perform.

3. Establishing a radiography procedures manual. The procedures manual shall include all of the provisions noted in this chapter as they apply to the X-ray equipment, use of such equipment, and the facility.

4. Reviewing and updating the procedures manual at least annually.

5. Assuring that technologists do not practice medicine or take X-rays without a specific written or verbal order or a prescription from a physician. All verbal orders must be followed by a written X-ray prescription.

6. Ascertaining that all X-ray personnel are familiar with the X-ray and ancillary equipment they use, and carry out their assigned duties correctly and conscientiously.

7. Providing safety rules which include:

   a. Restrictions of the operating techniques as required for safe operation of the particular X-ray apparatus, and

   b. Requirement that the X-ray operators demonstrate familiarity with the safety rules.

8. Instructing all individuals employed as radiologic technologists or limited permit X-ray technicians in the following:

   a. Health protection problems associated with exposure to radiation.

   b. Precautions and procedures to minimize exposure to both the patient and the operator.

   c. Responsibility to report promptly to the supervisor any condition which may lead to or cause a violation of the California Code of Regulations (CCR), title 17.

9. Advising individuals as to their radiation exposures, as applicable.

10. Regarding radiation safety, supervisors are responsible for assuring that:

    a. Careful collimation is used to restrict the X-ray beam to the area of clinical interest only. (The X-ray field should never be larger than the size of the film used.)

    b. Gonad shielding is used where and when appropriate. Policies regarding the use of gonad shielding must be made available to X-ray technical personnel.

    c. The X-ray room is cleared of all nonessential persons before X-ray personnel take X-rays.

    d. X-ray personnel stand behind a leaded shield or in a protective booth for every X-ray exposure.

    e. X-ray personnel wear personnel monitoring devices when required, and use these properly (on waist or collar; on the collar outside the apron when a leaded apron is worn).

    f. No individual is regularly or repeatedly used to hold patients. (Exception: In emergencies, when there is no other method of obtaining diagnostic radiographs, X-ray technical personnel may hold a patient.)

    g. Individuals who hold patients use appropriate protective apparel such as a leaded apron (at least 0.25 millimeters of lead equivalence), lead gloves, or lead shields.

11. Regarding technical aspects of X-ray examinations, supervisors are responsible for ascertaining that all operators of X-ray equipment:

    a. Use the fastest film-screen combination for the lowest dose practicable and commensurate with the objectives of the X-ray examination.

    b. Know exactly what examination and what view or views to take.

    c. Position the patient correctly for the required examination and view before making the actual exposure.

    d. Use high (optimum) kilovolt peak (kVp) and low milliampere-seconds (mAs) techniques for low dose radiography, consistent with obtaining a diagnostic quality image.

    e. Take steps to avoid patient motion by clearly instructing patients not to move, by using appropriate immobilization or positioning aids, and by keeping the patient comfortable and under constant observation.

    f. Use unexposed film that has not passed its expiration date.

    g. Make proper use of film markers.

h. Handle films carefully to prevent artifacts due to static electricity, fingerprints, crinkle marks, and other causes.

i. Ensure that the cassette closure provides good film-screen contact.

j. Keep the darkroom light-tight by sealing off light leaks.

k. Use only fresh (not exhausted) chemicals for film processing.

l. Make sure that the processing temperature is correct for the chemicals and film used.

m. Keep cassettes and screens clean.

n. Assure that the film processor is cleaned regularly.

o. Identify each film with the patient's name, date and film number, as appropriate.

p. Ensure that **no** sight development is done if films are hand developed.

NOTE: Failure to obtain diagnostic quality radiographs with the least radiation dose to the patient for the X-ray examination required means failure to meet the accepted standard of care.

C. TECHNOLOGIST RESTRICTIONS.

1. Certified radiologic technologists and limited permit X-ray technicians are prohibited from doing any of the following:

a. Taking radiographs without being adequately supervised.

b. Exposing human beings to X-rays without an order (prescription) from a licentiate of the healing arts. Order or prescription may be a "standing written order" or a verbal order followed by a written prescription for an X-ray examination.

c. Operating an X-ray machine without having proven that he/she can operate the particular X-ray equipment safely and effectively.

d. Using the X-ray unit without repeat film policies.

e. Taking X-rays that expose gonad areas without using a gonad shield. Specific written standing orders from the supervising licentiate must be followed regarding procedures in which the use of gonad shielding may interfere with the diagnosis.

f. Interpreting or making a diagnosis based on any radiograph.

g. Reporting of any diagnosis to a patient, except as ordered by a licentiate of the healing arts.

h. Performing venipuncture or arterial puncture or administering contrast materials. (Exception: Radiologic technologists may only complete an injection if a licensed physician and surgeon has performed the venipuncture or arterial puncture, has started the injection, and is readily available in case of emergency.)

i. Performing procedures not specifically authorized by a diagnostic radiologic technology certificate or a limited permit issued by the Department of Health Services, Radiologic Health Branch.

j. Taking X-rays without having conspicuously posted the authorizing document (certificate or permit) at the X-ray work place.

k. Taking X-rays when the certificate or permit has expired or been suspended.

l. Using any title or designation indicating or implying the right to practice any of the healing arts.

2. In addition to provisions applicable to the limited permit X-ray technicians noted in C. 1., limited permits specifically **exclude** authorization to do any of the following:

a. Operating fluoroscopy equipment during exposure of a patient to X-rays.

b. Operating portable or mobile X-ray equipment.

c. Performing procedures involving computerized tomography.

c. Performing mammography procedures.

d. Performing vascular procedures.

e. Performing procedures involving scanned projection radiography (digital radiography or digital tomography), or digital fluoroscopy.

D. TECHNOLOGIST/TECHNICIAN PERFORMANCE REQUIREMENTS.

Radiologic technologists and limited permit X-ray technicians shall comply with all of the following:

1. Follow the requirements of Section C, as appropriate.

2. Perform all assigned duties correctly and conscientiously.

3. Stand behind a protective barrier during the production of X-rays.

4. Wear a personnel monitoring device at the waist or on the collar during all working hours.

5. Not hold a film during the exposure.

6. Use optimum exposure techniques for the X-ray procedure to be performed.

7. Use optimum film and/or image processing techniques.

8. Follow standing orders and repeat film/image exposure policies.

9. Know what views are required and position patients correctly.

10. Collimate the X-ray field size to the area of clinical interest only.

11. Prevent patient motion by giving the patient clear instructions.

12. Handle films and cassettes carefully to eliminate artifacts.

13. Do not hold patients except in an emergency.

E. COMPLIANCE WITH REGULATORY PROVISIONS.

Supervisors shall be responsible for the following:

1. Radiographic equipment.

The owner/registrant/supervisor is responsible for all of the following:

a. Radiologic health and safety of all individuals under his/her jurisdiction.

b. Assuring that the X-ray equipment is at all times in safe operating order.

c. Registering X-ray equipment with the Radiologic Health Branch (RHB) in Sacramento. (To register equipment contact RHB and request form RH 2261A REGISTRATION OF RADIATION MACHINES.)

d. Assuring that only X-ray equipment identified by the manufacturer as designed for specific radiographic procedures is used to perform such X-ray procedures.

e. Establishing and maintaining a quality assurance (QA) program as specified in Appendix 14, pages 91 - 108, as appropriate.

2. Certification of X-ray personnel.

a. Radiologic technologists and limited permit X-ray technicians Individuals who hold valid authorizations (diagnostic certificates or specified radiography permits) from the California Department of Health Services, Radiologic Health Branch, may take X-rays on human beings only within the limits stated on the authorizing document.

Exceptions: Bona fide students enrolled in schools approved by California Department of Health Services or in approved on-the-job training programs.

b. Licentiates of the healing arts must possess:

(1) Radiology supervisor and operator certificates if they practice as radiologists.

(2) Radiography supervisor and operator permits if they do the following:

(A) Actuate or energize radiography X-ray equipment themselves; or

(B) Supervise certified radiologic technologists or limited permit X-ray technicians who perform radiography procedures.

F. THE DISPLAY OF DOCUMENTS.

1. Display of Certification Documents.

Section 30404 requires that certificates and permits issued by the Radiologic Health Branch of the California Department of Health Services be prominently displayed in the place of employment or work.

If a person is employed or works in more than one facility, a photocopy of the certification document must be displayed at each additional place of employment or work.

When facilities have large numbers of certified individuals, that facility may opt to display a single list that includes all of the following:

- o Names of certificate and permit holders
- o Certificate and permit numbers
- o Expiration dates
- o Notice as to where the actual certification documents are on file

2. Display of Laws and Regulations.

A current copy of the California Radiation Control Regulations and a copy of operating procedures applicable to working with X-ray machines and procedures must be posted or must be readily available to X-ray personnel.

3. Display of "Notice to Employees."

A current copy of Department Form RH-2364 "Notice to Employees" must be conspicuously posted. (Note: Copies of Form RH-2364 may be obtained from the Department of Health Services, Radiologic Health Branch - see address on page 69.)

G. RECORD KEEPING REQUIREMENTS.

Each user is required to maintain accurate and complete records as follows:

1. The results of each required calibration, survey, and test.

2. Each receipt, transfer, and disposal of a source of radiation (X-ray machine).

3. Radiation exposures of all individuals for whom personnel monitoring is required (see page 59).

4. The exposure records must be kept in a manner which includes all of the applicable information regarding occupational exposure.

5. Each personnel monitoring entry usually and advisably are changed once every month. Dose equivalents must be recorded in rems or millirems and dose equivalent rates in rems or millirems per hour.

6. Each required record of dose equivalent received by individuals must be kept (preserved) indefinitely. Each other required record must be preserved for a period of three years following the date of the occurrence that is the subject of such record.

7. The user is required to provide reports to any individual of his/her radiation exposure data.

H. INCIDENT NOTIFICATION REQUIREMENTS.

The State Department of Health Services must be notified when individuals are exposed to radiation, for other than prescribed medical purposes, in excess of the limits noted below.

Immediate notification means a prompt reporting by telephone (916) 445-0931 and confirmation by letter to the State Department of Health Services (see address on page 69). Twenty-four hour notification means telephoning the Department within 24 hours and a prompt confirming letter of the incident.

An overexposure of a film badge dosimeter or other type of dosimeter assigned to an individual is considered to be presumptive evidence of exposure to the individual. Regulations require the user/registrant/supervisor to investigate the conditions under which the overexposure occurred, and report the findings to the Radiologic Health Branch within 30 days.

1. Immediate notification is required if an individual has received:

   (a) A total effective dose equivalent of 25 rems (0.25 Sv) or more, or

   (b) An eye dose equivalent of 75 rems (0.75 Sv) or more, or

   (c) A shallow-dose equivalent to the skin or extremities of 250 rads (2.5 Gy) or more.

2. Twenty-four hour notification is required if an individual has received within 24 hours:

   (a) A total effective dose equivalent exceeding 5 rems (0.05 Sv), or

   (b) An eye dose equivalent exceeding 15 rems (0.15 Sv), or

   (c) A shallow-dose of equivalent to the skin or extremities exceeding 50 rems (0.5 Sv).

I. FORMAL TRAINING AND/OR INFORMATION A REGISTERED USER IS REQUIRED TO PROVIDE TO THE X-RAY PERSONNEL.

Education and training requirements for radiologic technology certification and for limited permits are governed by school standards set by the State. No informal training is permitted.

However, continuing education courses and supplementary training of persons who already possess certificates or permits is encouraged.

J. RESPONSIBILITIES REGARDING X-RAY EQUIPMENT.

1. X-ray machine registration requirements and vendor obligations.

X-ray equipment must be registered, within 30 days of acquisition, with the State of California Department of Health Services, Radiologic Health Branch, (see address on page 69). Request Form RH 2261, "Registration of Radiation Machines". There is an initial registration fee and a renewal fee collected biennially.

The sale, transfer, or disposal of any X-ray machine must be reported to the State of California Department of Health Services on forms available from the Radiologic Health Branch.

It is your responsibility to inform whomever acquires your X-ray machine that it must be registered with the Department of Health Services in his/her own name.

2. Renewal of individual certificates and/or permits.

Requests for renewal of any certificate or permit must be filed at least 30 calendar days prior to the expiration date of each certificate or permit, and must be on forms furnished by the Department. Renewal notices, before the expiration date of the certificate of permit, will be mailed to the last address listed in the Radiologic Health Branch's records.

3. X-ray equipment safety provisions.

No user shall operate or permit the operation of X-ray equipment unless the equipment and installation meet the applicable requirements of the California Radiation Control Regulations and are appropriate for the procedures to be performed [section 30305 (b) (3)]. A summary of radiographic safety provisions is found in Appendix No. 8, page 79.

4. Safety inspections.

In order to ensure compliance with the California Radiation Control Regulations, persons authorized by the State Department of Health Services are permitted, without a warrant, at all reasonable times, to inspect each user's X-ray machines, activities, facilities, premises, and records pertaining to radiography (and fluoroscopy), and associated supervisory activities.

5. X-ray room shielding provisions.

Structural shielding and other shielding problems are of such a specialized nature that it is appropriate and advisable to consult a qualified health physicist (or qualified radiological or medical physicist), should a shielding problem arise.

K. COMMUNICATION WITH RADIOLOGIC HEALTH BRANCH.

1. Communications.

All communications relating to California Radiation Control Regulations or Regulations Relating to Radiologic Technology should be sent to:

California State Department of Health Services
Radiologic Health Branch
601 North 7th Street. MS-178
Post Office Box 942732
Sacramento, CA 94234-7320

2. Change of Name or Address.

You must report any change of your name or address to the Department of Health Services, Radiologic Health Branch in Sacramento, within 30 days of that change [section 30403 (b)].

L. ENFORCEMENT AUTHORITY AND DISCIPLINARY ACTION.

1. Health and Safety Code.

a. Section 106970 (old section 25671.1) - states that it shall be unlawful for any person to direct, order, assist, or abet a violation of certification provisions.

b. Section 107075 (old section 25692) - states that any person who violates or aids or abets the violation of any of the provisions of the law or regulations is guilty of a misdemeanor.

APPENDIX NO. 1

UNITS OF RADIATION DOSE

For the purpose of radiation hazard evaluation, two units of radiation dose and dose equivalent have been introduced to account for the several methods of measuring and assessing the effects of different types of radiation. Two of the most important quantities and corresponding units regarding the use of radiography equipment are:

A. Absorbed dose - rad (or gray - SI units)

B. Dose equivalent - rem (sievert - SI units)

Definitions:

Gray (Gy) is the SI unit of absorbed dose. One gray is equal to an absorbed dose of 1 joule/kilogram (100 rads).

Rad is the special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joule/kilogram (0.01 gray).

Rem is the special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor (1 rem = 0.01 sievert).

Sievert is the SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the quality factor (1 Sv = 100 rems).

Quality factor (Q) for X-, gamma, or beta radiation is 1. Absorbed dose in rad is equal to 1 rem or the absorbed dose in gray is equal to 1 sievert.

A. The rad.

The rad, an acronym for Radiation Absorbed Dose, is the special unit of absorbed dose. The quantity significant in biological and medical work is not the amount of radiation passing through a point in air; rather, it is the amount of energy absorbed by the substance at a particular point, that is, the absorbed dose. An absorbed dose of one rad corresponds to the absorption of 100 ergs of energy per gram of tissue or other material and is of primary importance in radiation dosimetry.

B. The rem -- dose equivalent.

The unit " rem" was devised to allow for the fact that the same absorbed dose in rads delivered by different kinds of radiation does not produce the same degree of biological effect; some types of particulate radiation are biologically more effective than others. The determination of dose equivalent is especially important when considering doses to critical organs. Occupational dose equivalent limits are all stated in terms of rems.

It is important to make a distinction between radiation dose measured in rads and dose equivalent measured in rems; however, their biological impact is evaluated in rems.

C. Dose rate.

An important aspect of irradiation is the radiation dose rate, which is the radiation dose delivered per unit time. Dose rate is expressed in rems per hour, the absorbed dose in rads per hour (rad/h).

APPENDIX NO. 2

TIME - DISTANCE - SHIELDING

There are three basic principles, which can be used singly or in combination, to reduce dose to X-radiation: time, distance, and shielding.

A. Time.

Basic principle: Keep the time of the X-ray exposure as short as possible.

During radiographic examination, the dose to the patient is directly related to the dose rate and the duration (time) of the exposure. **The operator exposure to scattered radiation is directly proportional to patient radiation dose.**

B. Distance.

Basic principle: Keep the distance between the source of exposure (X-ray tube, or any scattering medium such as a patient) and the exposed individual as large as practicable.

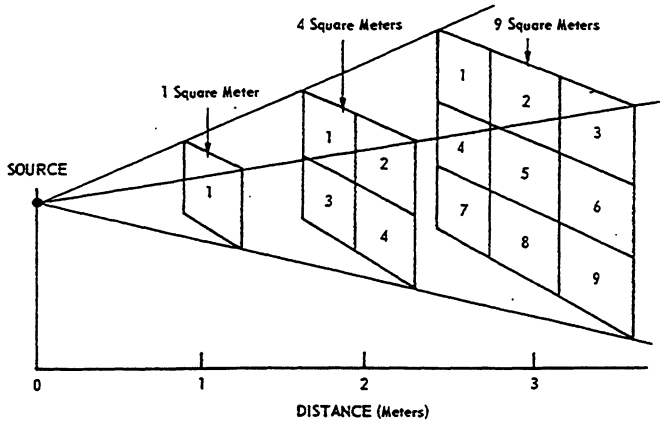
The intensity of radiation varies inversely as the square of the distance. It is obvious that the farther the person is from the X-ray source, the less radiation dose per unit of time he/she will receive.

The inverse square law: At points distant from a common source of X-radiation, the intensities of radiation at these points vary as the square of their respective distances from the X-ray source.

As one moves farther away from an X-ray source the radiation he/she receives will be less because the X-ray beam **diverges** as it moves away from its source. The inverse square law can be expressed by a mathematical relationship:

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2} \quad \text{or} \quad I_1 (D_1)^2 = I_2 (D_2)^2$$

where: I_1 - intensity at distance D_1
I_2 - intensity at distance D_2



It is easy to see that if the distance from an X-ray source is doubled, the radiation intensity is reduced to 1/4 of the intensity at the original distance. If the distance from the source is tripled, the intensity is reduced to 1/9. If the distance from the source is quadrupled, the intensity is 1/16, etc. On the other hand, if the distance from the source is halved, then the exposure intensity is quadrupled. Most radiation sources are point sources, the X-ray tube target, for example. However, the scattered radiation generated within a patient during an X-ray exposure comes from an extended area.

C. Shielding.

Basic principle: Insert shielding material between the source of the radiation and the exposed person, as applicable.

Shielding refers to the different means used to stop radiation or to prevent exposure to it. To be able to apply shielding methods, one must have some understanding of the manner in which X-radiation is attenuated (absorbed) in an absorbing medium. Energy is lost by three methods:

- **The photoelectric effect.** A collision between a photon of X-radiation and an orbital electron of an atom, where the electron is knocked out of its orbit and the photon loses all its energy.
- **Compton scattering.** Interaction of a photon of X-radiation with an orbital electron of the absorber atom producing a recoil electron and a photon energy which is less than that of the incident photon.
- **Pair production.** Incident photon is annihilated in the vicinity of the nucleus of the absorbing atom with subsequent production of an electron and positron pair.

The photoelectric effect is the most important at low energies (up to 100 kVp) which are utilized to produce radiographic images. As X-rays pass through an absorber, their decrease in number is governed by:

- The energy of the radiation
- The specific medium (density of the material)
- The thickness of the absorber traversed

The third fact is so important that it merits further clarification. Scattered radiation is present to some extent whenever an attenuating medium is in the path of radiation. **The attenuator (patient during irradiation) then acts as a new source of radiation.** Frequently, room walls, the floor, and other solid objects are near enough to a source of radiation to make scatter appreciable.

D. Half-value layer (HVL).

The half-value layer (HVL) is used in two different situations:

- Determining the **quality** (average penetrating ability of an X-ray beam)
- Determining the **barrier thickness** (amount of shielding needed to attenuate radiation to the required degree).

The quality (average penetrating ability) of an X-ray beam is usually specified in terms of a half-value layer (HVL). **The HVL is defined as the thickness or layer of a specified material which attenuates the X-ray beam to such an extent that the exposure rate is reduced to one half. It is commonly expressed in millimeter thicknesses of aluminum.** A higher HVL for an X-ray beam means that it can penetrate a given thickness of material (including human tissue) to a greater extent than a lower HVL layer. As indicated in Chapter II, page 11, X-ray tubes have a minimum HVL requirement so that attenuation/absorption of X-rays in the body is minimized yet image quality is not affected adversely.

The **barrier thickness** is usually expressed in terms of inches or millimeters of a specified material (usually lead) required to attenuate radiation to a specified energy (in kilovolts) to a degree where persons on the other side of that barrier will not be exposed to greater than permissible amount of radiation.

APPENDIX NO. 3

STEPWISE EFFECTS OF RADIATION INJURY

	Time	Exposure to radiation
S H O R T T E R M	10^{-12} seconds	Physical effects at molecular level ↓ Absorption of radiation energy ↓ Ionization and excitation process ↓
	10^{-9} seconds	Primary radiochemical reactions Formation of active radicals ↓
	10^{-8} seconds	Disruption of molecular bonds Biochemical changes in cells ↓
	seconds minutes	**Cellular damage** ↓ Functional damage of cells ↓ Damage to genetic structures (mutations) ↓
	minutes hours	**Cell death** Functional damage and morphological changes in cells ↓ Appearance of atypical cells ↓
	hours months	**Pathological changes in the whole organism** ↓ Functional disturbances ↓ Morphological changes ↓ Destruction of the organism
L O N G T E R M	lifetime of the organism	**Late somatic changes** - cancer - leukemia - life span shortening - cataract formation ↓
	future generations	**Genetic changes**

APPENDIX NO. 4

SPECIAL CONSIDERATIONS CONCERNING X-RAY EXAMINATION OF THE PREGNANT OR POTENTIALLY PREGNANT PATIENT

A. Scheduling of X-Ray Examinations for Women of Childbearing Capability.

The radiobiological literature suggests that there is no time period during which a radiological examination can be conducted with **no** biological risk accruing to the real or potential embryo/fetus or to a future fertilized ovum. This statement is predicated on three assumptions:

- o There is always a small potential for adverse biological effects to occur following exposure to X-radiation
- o There is no threshold for such effects
- o Such effects are directly proportional to absorbed radiation dose

Major adverse effects include leukemia, congenital malformations, cancer induction, resorption or death of the embryo, and genetic considerations.

Evidence from the literature indicates that ovarian cells may be affected prior to fertilization of the embryo, and the embryo may be affected at all times after fertilization. While the **kind** of effect may vary with the stage of embryo/fetus development and in fact one or more effects may overlap or superimpose, there is no time that radiation is absolutely safe.

Since there is no absolutely "safe" period for the conduct of diagnostic X-ray examinations in fertile women, the question arises, should women who have a potential to be pregnant have abdominal area X-ray examinations scheduled according to their menstrual period or postponed to reduce the possibility of exposing an unsuspected embryo/fetus to diagnostic levels of X-radiation?

Recommendation:

Diagnostic X-ray examinations that have been requested after full consideration of the clinical statues of the patient, including the possibility of pregnancy, need not be postponed or selectively scheduled, except in those few instances where the examination may be related to the patient's current illness.

This statement is not substantially different from the 10 and 14 day rules previously suggested by the ICRP and NCRP which state that 10 or 14 days after the onset of menses it is improbable that a woman would be pregnant and thus these are "safer" times to perform X-ray examinations.

B. Therapeutic Abortions.

Another important issue facing diagnostic radiology is the question of whether or not therapeutic abortions should be recommended and performed because of exposure of the embryo/fetus to diagnostic levels of X-radiation?

Conclusion:

Interruption of pregnancy is never justified because of radiation dose to embryo/fetus to a diagnostic X-ray examination. This includes radiation doses from both abdominal and peripheral examinations.

APPENDIX NO. 5

OCCUPATIONALLY EXPOSED WOMEN OF CHILDBEARING AGE

Section 30255 of the California Radiation Control Regulations states that each user/supervisor must instruct radiologic technologists (occupationally exposed individuals) in the health protection problems associated with radiation. A special situation arises with occupationally exposed young women. The precautions should be taken to limit exposure to young women, especially if they could be pregnant. Exposure to the abdomen of such workers to X-rays would involve radiation dose to the embryo or fetus.

Radiology or Radiography Supervisor and Operators are responsible for the following:

A. Following California Radiation Control Regulation requirements (section 20.1208, 10 CFR 20 incorporated in California Regulations by reference).

B. Providing the employee with reasons for the requirements.

C. Explaining the options.

A. Dose to an embryo/fetus.

1. Definition:

Declared pregnant woman means a woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception.

Deep-dose equivalent, which applies to external whole-body exposure, is the dose equivalent at a tissue depth of 1 cm (100 mg/cm^2).

Embryo/fetus means the developing human organism from conception until the time of birth.

2. Regulatory provisions (section 20.1208, 10 CFR 20):

a. The licensee (user/supervisor) shall ensure that the dose to an embryo/fetus during the entire pregnancy, due to occupational exposure of a declared pregnant woman, does not exceed 0.5 rem (5 mSv).

b. The licensee (user/supervisor) shall make efforts to avoid substantial variation above a uniform monthly exposure rate to a declared pregnant woman so as to satisfy the limit in paragraph (a) of this section.

c. The dose to an embryo/fetus shall be taken as the sum of:

(1) The deep-dose equivalent to the declared pregnant woman; and

(2) The dose to the embryo/fetus from radionuclides in the embryo/fetus and radionuclides in the declared pregnant woman.

d. If the dose to an embryo/fetus is found to have exceeded 0.5 rem (5 mSv), or is within 0.05 rem (0.5 mSv) of this dose, by the time the woman declares the pregnancy to the licensee (user/supervisor), the licensee (user/supervisor) shall be deemed to be in compliance with paragraph (a) of this section if the additional dose to the embryo/fetus does not exceed 0.05 rem (0.5 mSv) during the remainder of the pregnancy.

B. Reasons for Requirements.

Once a pregnancy becomes known, radiation dose of the embryo-fetus shall be no greater than 0.05 rem (50 mrems) in any month (excluding medical exposure).

Some studies have shown that there is an increased risk of leukemia and other cancers in children if the expectant mother was exposed to a significant amount of radiation. The Radiologic Health Branch wants women employees to be aware of any possible risk so that the women can take steps they think appropriate to protect their offspring.

It is strongly suggested that the instruction be given both orally and in writing. Also, each individual should be given an opportunity to ask questions, and each individual should be asked to acknowledge in writing that the instruction has been received.

The following facts should be given to the woman employee:

- The first three months of pregnancy are the most important as the embryo-fetus is most sensitive to radiation at this time
- In most cases of occupational exposure, the actual dose received by the embryo-fetus is less than the dose received by the mother, because some of the dose is absorbed by the mother's body
- At the present occupational dose equivalent limits, the risk to the unborn baby is considered to be small, but experts disagree on the exact amount of risk
- There is no need for women to be concerned about sterility or loss of ability to bear children
- The 0.5 rem (500 mrems) dose equivalent limit applies to the full nine months of pregnancy
- Once a pregnancy becomes known, radiation dose of the embryo-fetus shall be no greater than 0.05 rem (50 mrems) in any month

C. Options.

The available options are usually:

- Delay having children as long as one works around radiation
- If pregnant, leave the job. (If this is a realistic option, it should be done immediately - the embryo-fetus is most sensitive to radiation at the outset of pregnancy and continues to be radiosensitive throughout the gestation period.)
- Could be temporarily reassigned to tasks which involve less risk of being exposed to radiation
- Use protective apron (full-size, half-size, wrap-around, or any other protective clothing appropriate to the situation) while actually exposing patients
- Never hold patients
- Not perform portable or surgical X-ray procedures
- Not assist in special procedures or fluoroscopic procedures
- Use two personnel monitoring devices such as a pocket chamber worn at the abdomen and film or TLD badge worn at the regular place
- Whenever possible stay out of the X-ray room and behind protective barriers while the X-ray beam is activated

Addendum to: **SYLLABUS ON RADIOGRAPHY RADIATION PROTECTION**

Page 76 The last bullet under *The following facts should be given to the female employees* should read:

If the dose to the embryo/fetus is found to be 0.5 rem $\pm$ 0.05 rem (5 mSv $\pm$ 0.5mSv)) at the time the woman declares her pregnancy, she shall be deemed in compliance if the additional dose to the embryo/fetus does not exceed 0.05 rem (0.5 mSv) during the remainder of the pregnancy.

APPENDIX NO. 6

RELATIVE SPEEDS OF INTENSIFYING SCREENS

Screen Classifications

Screen Type	Detail	Medium Speed	High Speed
Rare-earth (Green Light or Blue Light)	80-100	250-300	400-800+
Calcium Tungstate (Blue Light)	80-100	100-200	250-300

Screen Characteristics

Detail	Medium Speed	High Speed
High Contrast with Excellent Bone Detail	High Contrast with Excellent Detail	High Contrast with Good Detail

NOTE: The actual system speed is dependent upon the type of film used. Illustrated below are examples of how the system speed is subject to change.

Screen	Film Type	Relative Speed
Kodak Lanex Medium Rare-earth	Kodak TMAT H 600+	400
	Fuji RXOH	400
	Kodak TMAT LG	300
	Cronex 8	250
	Valca VOG	200
Dupont Hi Plus Calcium Tungstate	Valca RP 90	300
	Kodak BB	250
	Cronex 4	250
	Kodak XG	125
	Fuji RX	125

NOTE: For comparison purposes, medium speed calcium tungstate screens are arbitrarily assigned a "speed" of 100. "Speed" values are approximations for calculating exposure adjustments required to match radiographic density. For example: Changing from medium-speed calcium tungstate screens (speed of 100) to regular rare-earth screens (speed of 400) will result in a reduction of 75 percent in the exposure settings and patient dosage required for the same density of the radiographic film of comparable diagnostic quality.

APPENDIX NO. 7

PERSONNEL MONITORING DEVICES -- SUMMARY

A. FILM BADGE.

Radiation detected: X-rays, gamma, beta, thermal neutrons, fast neutrons.

Range: 0.0 to 700 rad.

Minimum energy detected: 10 keV for gamma rays, 200 keV for beta rays.

Advantages: Inexpensive, gives estimates of integrated dose, provides permanent record, allows objective review, detects problems.

Possible disadvantages: Moderate directional dependence, strong energy dependence for low energy X-rays, false readings produced by heat, pressure, and certain vapors.

B. THERMOLUMINESCENT DOSIMETER (TLD).

Radiation detected: X-rays, gamma, beta, thermal neutrons, fast neutrons.

Range: 10 mrads to 10^5 rad.

Minimum energy detected: 10 keV.

Advantages: Infinite shelf life within the useful range, small size and low directional dependence, small energy dependence, reusable, inexpensive, give estimate of integrated dose over long periods.

Possible disadvantages: System supplied as commercial service, cancellation of dose upon reading, dose range depends on the sensitivity of the reader, radiation detected depend on type of TLD material, increased sensitivity with each use, fading, subjective information of exposure is not available.

C. POCKET IONIZATION CHAMBER.

Radiation detected: X-rays, gamma, beta, thermal neutrons, fast neutrons.

Range: 0.001 to 2000 rads (theoretical); for X-ray use: 0.001 to 200 millirads.

Minimum detected energy: 30 keV for gamma rays, 20 keV for fast neutrons.

Advantages: Yield fairly accurate information quickly, small size, low directional dependence, reasonably uniform in response to radiation in the energy range of 50 keV to 2 MeV, economical for long-term use, requires little maintenance, reusable.

Possible disadvantages: No permanent record, frequent reading tabulation, recharging may be required, subject to accidental discharge (through shock and electrical leakage), range of measurement is limited.

APPENDIX NO. 8

OVERVIEW OF CALIFORNIA RADIATION CONTROL REGULATIONS.

The California Radiation Control Regulations are contained in the California Code of Regulations (CCR), title 17, and are generally referred to as "laws" or "statutes." The Regulations are administered by the California Department of Health Services, Radiologic Health Branch (RHB).

The Regulations are not recommendations but provisions that must be complied with. Section 115220 (old section 25866) of the Health and Safety Code specifically states that any person who violates any part of the provisions of these regulations is guilty of a misdemeanor.

A. Registration of x-ray machines

Item	Provision	Section
-X-ray machine registration	Must be registered	30108
-Initial registration	Must be registered with the Department (Radiologic Health Branch) in Sacramento within 30 days of acquisition	30110
-Renewal of registration	Registration must be renewed during July of every even-numbered year	30111
-Report of change	The registrant shall report in writing to the Department (Radiologic Health Branch), within 30 days, any change in: registrant's name, address, location of the installation, or receipt, sale, transfer, disposal, or discontinuance of use	30115
-Vendor obligation	Must inform the receiver of registration requirement	30118
-Records to be maintained	Shall keep records of receipt, transfer, or disposal of X-ray equipment	30131
-Fees	"High priority radiation"	30145(a)
-Payment of fees	Must pay the required fee	30146

B. General definitions

Item	Provision	Section
-Department	The State Department of Health Services (usually Radiologic Health Branch)	30100(c)
-Human use	Administration of radiation to human beings	30100(f)
-Installation	The place/location where X-ray machine is located	30100(g)
-Other official agency	An agency with which the Department has entered into agreement to carry out inspections of X-ray equipment	30100(j)
-Person	Any individual, corporation, partnership, firm, group, etc.	30100(k)

B. General definitions (continued)

Item	Provision	Section
-Personnel monitoring equipment	Film or TLD badges, pocket chamber or dosimeter	30100(l)
-Possessing a reportable source of radiation	Having physical possession or having control of an X-ray equipment	30100(n)
-Radiation	X-rays or X-radiation	30100(o)
-Radiation machine	Any X-ray machine capable of producing radiation	30100(p)
-Registrant	Any person who has registered with the Department an X-ray equipment	30100(r)
-Reportable source of radiation	Any X-ray machine, when installed in such manner as to be capable of producing radiation	30100(s)
-Source of radiation	A single radiation machine	30100(v)
-This regulation	California Code of Regulations (CCR), title 17, chapter 5, subchapter 4	30100(y)
-User	Any person who has registered with the Department an X-ray equipment	30100(z)
-Worker	Any individual who use X-ray equipment to expose patients to X-rays	30100(aa)
-Dead-man switch	Terminates exposure when pressure is released	30306 (d)
-X-ray tube housing	Diagnostic type, <100 millirads leakage at one meter	30306 (e)
-Filter	Material placed in the useful beam to absorb preferentially the less penetrating radiation	30306 (f)
-Leakage radiation	All radiation coming from tube housing except the useful beam	30306 (h)
-Protective barrier	Attenuating materials used to reduce radiation exposure	30306 (i)
-Primary protective barrier	Used to attenuate the useful beam to the required degree	30306 (j)
-Scattered radiation	Radiation that, during passage through matter, has been deviated in direction	30306 (k)
-Secondary protective barrier	Used to attenuate stray radiation to the required degree	30306 (l)
-Stray radiation	Includes leakage and scattered radiation	30306 (n)
-Shutter	A device, generally of led, fixed to an X-ray tube housing to intercept the useful beam	30306(m)
-Useful beam	Radiation which passes through the X-ray window, aperture, cone or other collimating device	30306 (p)
-Absorbed dose	The energy imparted by ionizing radiation per unit mass of irradiated material [The unit of absorbed dose are the rad and the gray (Gy)]	20.1003

B. General definitions (continued)

Item	Provision	Section
-Adult	An individual 18 or more years of age	20.1003
-ALARA	Making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical	20.1003
-Collective dose	Is the sum of the individual doses received in a given period of time by a specified population to a specified source of radiation	20.1003
-Controlled area	An area, outside of a restricted area access to which can be limited by the licensee for any reason	20.1003
-Declared pregnant woman	A woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception	20.1003
-Dose equivalent	The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest [The unit of dose equivalent are the rem and the sievert (Sv)].	20.1003
-Embryo/fetus	The developing human organism from conception until the time of birth	20.1003
-Exposure	Being exposed to ionizing radiation or to radioactive material	20.1003
-Eye dose equivalent	Applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 centimeters (300 mg/cm^2)	20.1003
-Individual	Any human being	20.1003
-Member of the public	An individual in a controlled or unrestricted area. An individual is not a member of the public during any period in which the individual receives an occupational dose	20.1003
-Minor	An individual less than 18 years of age	20.1003
-Nonstochastic effect	Health effect, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a nonstochastic effect (also called a deterministic effect)	20.1003
-Occupational dose	The dose received by an individual in a restricted area or in the course of employment	20.1003

B. General definitions (continued)

Item	Provision	Section
-Stochastic effects	Health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects	20.1003
-Unrestricted area	An area, access to which is neither limited nor controlled by the licensed dentist	20.1003
-Whole body	For purposes of external exposure, head, trunk (including male gonads), arms above the elbows, or legs above the knee	20.1004
-Gray (Gy)	Is the SI unit of absorbed dose. One gray is equal to an absorbed dose of 1 joule/ kilogram (100 rads)	20.1004(a)
-Rad	The special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joule/kilogram (0.01 gray)	20.1004(a)
-Rem	The special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor (1 rem = 0.01 sievert)	20.1004(a)
-Sievert	The SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the quality factor (1 rem = 0.0. sievert)	20.1004(a)
-Survey	Evaluation of radiological conditions and potential hazards	10 CFR 20 20.1003

C. Radiographic equipment provisions

Item	Provision	Section
-X-ray tube housing	Diagnostic type, <100 mrads leakage at one meter	30306 (e)
-Diaphragms, cones adjustable collimators	Must be able to restrict the beam to the area of clinical interest	30308 (a)(2)
-Adjustable collimation	Must be accurate within 2 percent of the source-film distance	30308 (a)(2)
-Light field/X-ray field	Must coincide within 2 percent	30308 (a)(2)
-Device to terminate exposure	Terminate after a pre-set time	30308 (a)(4)
-Exposure switch	Dead-man type	30308 (a)(5)

D. Building Code provisions

Item	Provision	Section
-Control panel	Must have device to give positive indication of the production of X-rays, if tube is energized	30308(a)(6)
	Must have device indicating kVp, mA, time or must have automatic timer	30308(a)(7)
-Tabletop or upright film holder	Must not exceed 1 mm Aluminum equivalent at 100 kVp	30308(a)(9)
-Dead-man switch	Terminates exposure when pressure is released	30306 (d)
-Operator station	Behind a protective barrier either in a separate room, in a protective booth, or behind a shield which will intercept the useful beam and any radiation which has been scattered only once	Building Code 2-9104 (a)
-Patient observation	The operator shall observe and communicate with the patient without leaving the shielded position at the control panel	Building Code 2-9104 (b)
-Observation window	Must provide radiation attenuation equal to that required in the surrounding barrier	Building Code 2-9104 (b)

E. Mobile radiographic equipment provisions

Item	Provision	Section
-Mobile radiographic equipment	Where applicable, must meet the same requirements as a stationary unit	30309 (a)(1)
-Exposure switch	Shall be of dead-man type and be so arranged that the operator can stand at least 6 feet away from the useful beam	30309 (a)(2)
-Operational procedures	Where applicable, must meet the same provisions as a stationary unit of Section 30308 (b), except (b) (5)	30309(b)(1)
-Source-to-skin distance	Must not be less than 12 inches	30309 (b)(2)
-Personnel monitoring	Is required for all persons operating mobile X-ray equipment	30309 (b)(3)

APPENDIX NO. 9

CALIFORNIA ENTRANCE SKIN RADIATION DOSE AVERAGES

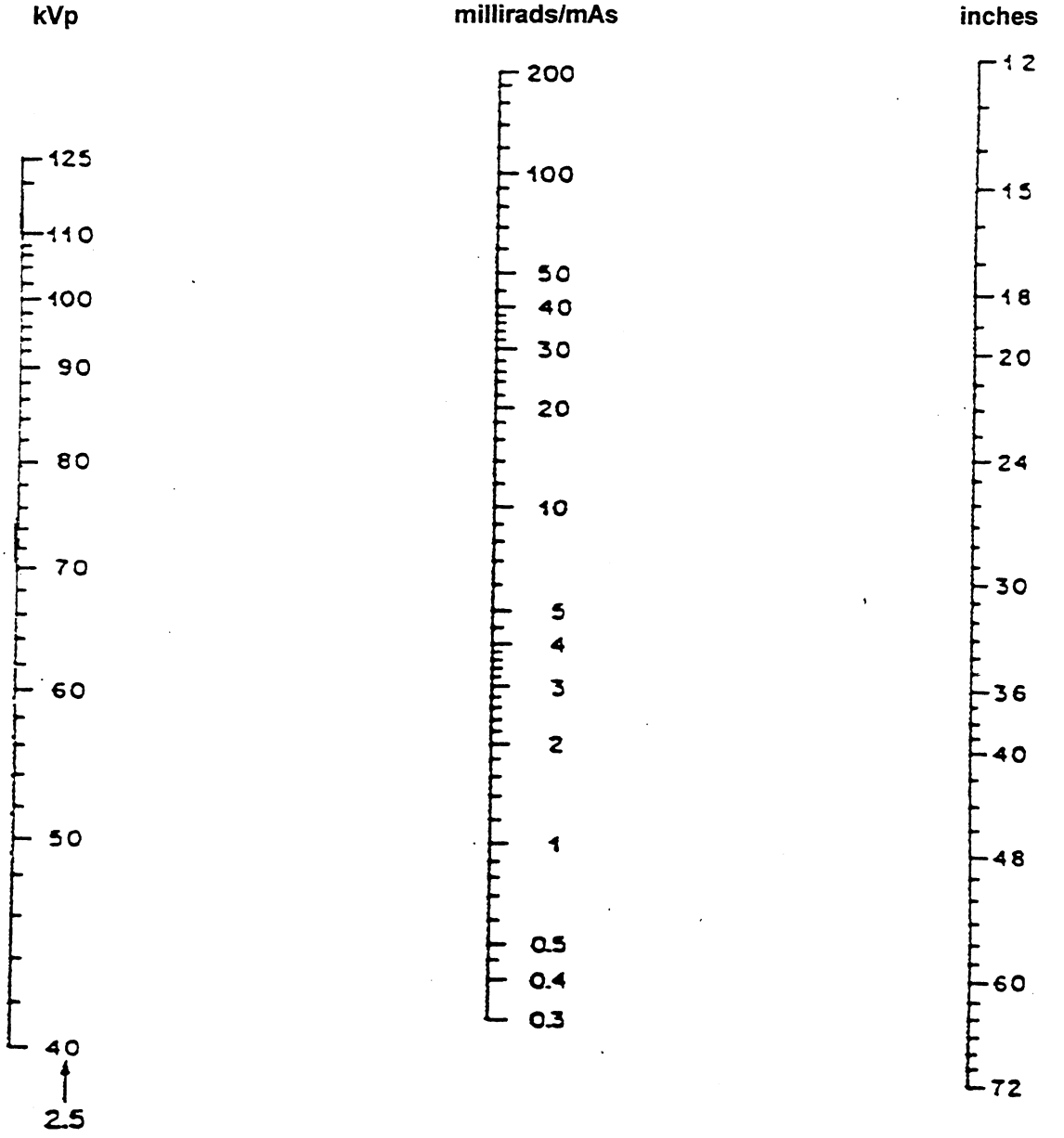
Patient skin radiation doses in millirads noted below should not be exceeded.

Description	Cm	Inches	SID	Grid	200 Speed System	400 Speed System	Other
Chest-PA	23	9	72	w/o	15	5	
	23	9	72	w	25	15	
	23	9	40	w/o	38	20	
Peds Chest-AP	10	4	40	w/o	--	15	
	7	3	40		--	5	
Cervical Spine-AP	13	5	40	w	130	95	
	13	5	40	w/o	40	--	
Cervical Spine-Lat.	13	5	72	w/o	40	-	
	13	5	72	w	--	125	
Thoracic Spine-AP	23	9	40	w	370	200	
Lumbar Spine-AP	23	9	40	w	440	350	
	23	9	40	w	550	300	
Full Spine-AP	23	9	72	w	250	140	
	23	9	72	w	300	--	Gradient Hi Plus
	23	9	72	w	--	190	Rare-earth
Abdomen-AP	23	9	40	w	490	300	
Skull-Lateral	15	6	40	w	140	70	
Sinuses-Lateral	15	6	36	w	65	30	
Shoulder-AP	18	7	40	w	60	30	
	18	7	40	w/o	--	15	
Elbow-AP/Lat.	9	3.5	40	w/o	16	7	Rare-earth
Hand-AP	3	1.2	40	w/o	12	5	Detail
Knee-AP/Lat.	13	5	40	w	90	25	
Ankle-AP		4	40	w/o	17	8	
Foot-AP	7	2.7	40	w/o	15	10	
Podiatric Foot-DP	10	4	28	w/o	35	20	75-Par Speed 50-Detail

APPENDIX NO. 10

NOMOGRAM FOR ESTIMATION OF SKIN RADIATION DOSE

A nomogram for determining the approximate radiation intensity produced by a radiographic unit (full-wave rectified waveform) under variable operating conditions. A straight edge through appropriate points on the outside scales will intercept the middle scale at the approximate skin exposure value. Examples of nomogram use appear on the following page.



NOMOGRAM USE

1. For an abdominal film taken at a focus-skin distance of 40 inches, with exposure settings of 50 mAs at 80 kVp with 2.5 mm Aluminum filter, what would be the approximate radiation dose to the patient?

Solution:

With a straight edge, connect the two outside scales of the nomogram at 80 kVp with 2.5 mm Al filter and 40 inch FSD to give an exposure of 5 mrads/mAs. Multiply (5 mrads/mAs) X 50 mAs to give an approximate radiation dose of 250 mrads.

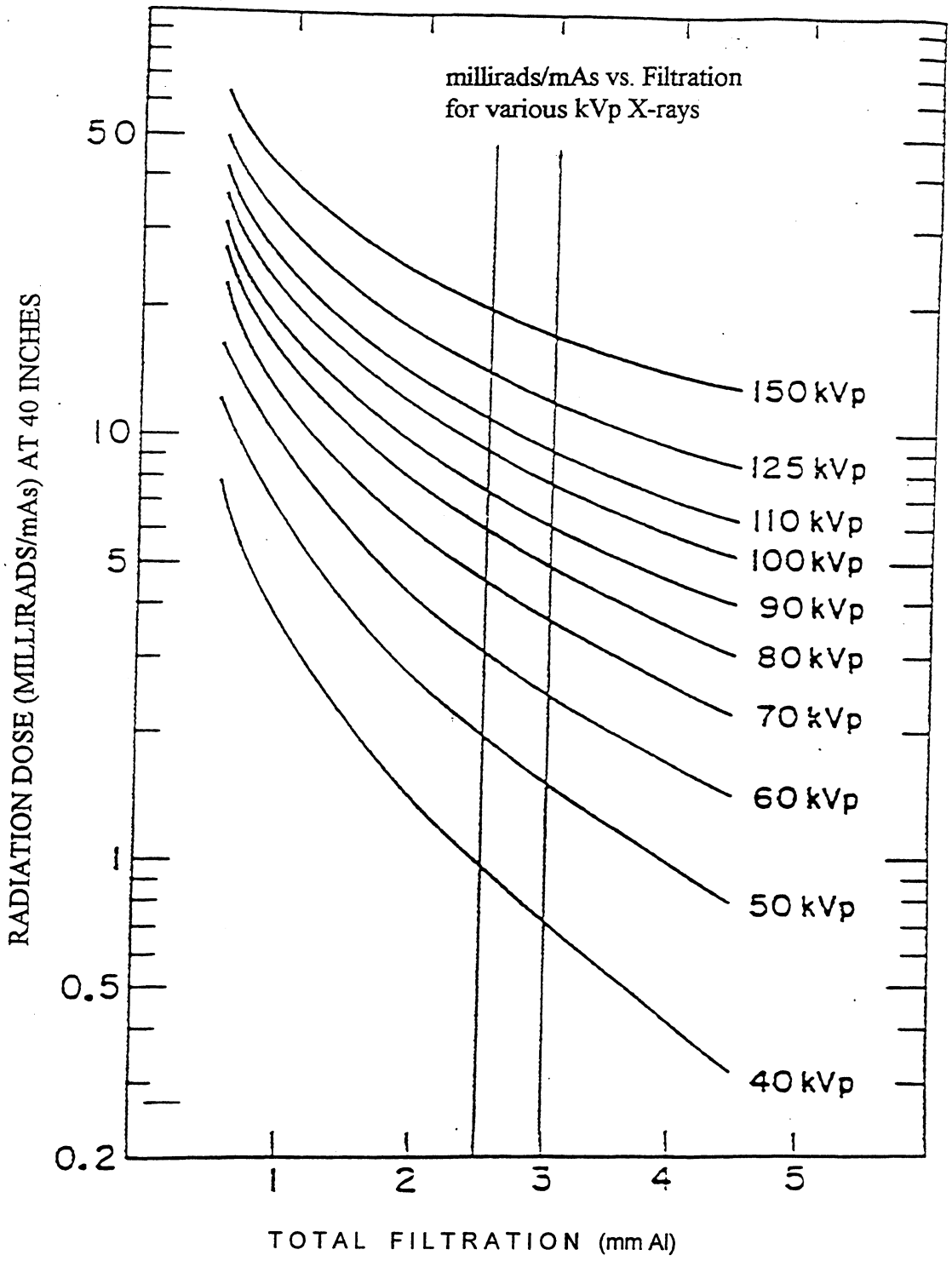
2. A chest X-ray is taken with a focus-skin distance (FSD) of 72 inches using settings of 500 mA and 0.01 seconds at 125 kVp with a filter of 2.5 mm Aluminum. What is the approximate radiation dose to the patient?

Solution:

With a straight edge connect the two outside scales of the nomogram at 72 inch FSD and 125 kVp to give an exposure of 4.5 mrads/mAs. Multiply the mA of 500 times the exposure time of 0.01 seconds to give an mAs of 5. Multiply 5 mAs times the exposure factor of 4.5 mrads/mAs to give a patient exposure of (5)(4.5) = 22.5 mrads.

COMPARISON OF EXPOSURES (in mrads per mAs) FOR SINGLE PHASE AND THREE PHASE X-RAY EQUIPMENT AT A FOCUS-SKIN-DISTANCE OF 22 INCHES

Kilovoltage	Single-phase	Three-phase	Percent difference single- vs. three-phase
50	4.8	6.5	35
60	8.3	11.2	35
70	13.1	17.7	35
80	16.7	22.6	35
90	22.6	30.6	35
100	27.4	37.1	35
125	45.2	61.2	35



The approximate exposure at 40 inches from a radiographic unit for various conditions of kilovoltage (kVp) and total filtration.

APPENDIX NO. 11

SPECIFIED ORGAN DOSES FROM DIAGNOSTIC RADIOLOGY

		Organ Dose (μGy)*						
Examination	Films #	Thyroid	Active Marrow	Lung	Breast	Testes	Ovaries	Embryo
Chest	1.5	60	40	200	140	-	0.6	0.6
Ribs	3.0	1,500	450	3,000	4,100	-	4	5
Shoulder	1.8	600	60	350	750	-	-	-
Skull	4.1	2,200	300	20	-	-	-	-
Paranasal sinuses	4.0	7,900	1,200	100	100	10	20	-
Cervical spine	3.7	4,000	100	150	-	-	-	-
Thoracic spine	2.1	800	450	4,000	5,400	-	10	1
Lumbar spine	2.9	3	1,200	1,400	-	70	4,500	4,100
Lumbosacral spine	3.4	1	2,200	350	-	450	6,400	6,400
Pelvis	1.3	-	250	10	-	550	1,500	2,000
Hip	2.0	-	150	-	-	3,700	800	1,300
Mammo-graphy	2.0	-	-	-	1,000	-	-	-
KUB	1.7	1	500	100	-	150	2,100	2,600
Upper GI	4.3	70	1,200	5,000	550	4	450	500
BE	4.0	2	3,000	500	-	600	7,900	8,200
IVP	5.5	-	1,200	350	-	500	6,400	8,200
CT brain	5.0	-	1,400	-	-	70	70	-

Average examinations, excluding contribution of fluoroscopy.
* 10 μGy = 1 millirad

APPENDIX NO. 12

RELATIVE SOMATIC DETRIMENT OR CARCINOGENIC POTENTIAL FROM COMMON RADIOGRAPHIC EXAMINATIONS (in arbitrary units)

RELATIVE SOMATIC DETRIMENT	Male	Female	
10			
9			
8			
7			
6			
5			
		450	Mammography
4			
	350		Barium enema
3		300	Thoracic spine
	300		Upper GI, Lumbosacral spine
2	200		Lumbar spine
	180		Thoracic spine, ribs
	160		Full spine (chiropractic)
	150	150	Barium enema
		140	Lumbosacral spine
1		100	Full spine (chiropractic)
	50		KUB, skull cervical spine
		50	Cervical spine, skull, shoulder
	40		Shoulder, hip
	30		Chest, hip
	20		Chest

APPENDIX NO. 13

SOME POSSIBILITIES FOR DOSE REDUCTION IN MEDICAL DIAGNOSTIC USES

Type of procedure	A c t i o n	Reduction factor
All types	Eliminate medically unnecessary procedures	1.2
	Proper processing of films	1.1 - 1.3
	Introduction of quality assurance program (general)	2.0
Radiography (general)	Decrease of rejected films through quality assurance program	1.1
	Beam collimation	1.5 - 3.0
	Increasing peak kilovoltage	1.5
	Use of rare-earth screens	2.0 - 4.0
	Increasing filtration	1.7
	Rare-earth filtration	2.0 - 4.0
	Use of carbon fiber material	2.0
	Replacement of $CaWO_4$ screens with spot film technique	4.0
	Entrance radiation dose guidelines	15.0
	Gonad shielding (to gonads)	100.0
(pelvimetry)	Use of CT tomogram or scout view	5.0 - 10.0
Fluoroscopy	Acoustic signal related to dose rate	1.3
	Replacement of film/screen technique	2.0 - 5.0
	Variable aperture iris on TV camera	3.0
	High and low dose switches	1.5
	Radiologist technique	2.0 - 10.0
Digital radiography	Decrease in contrast resolution	2.0 - 3.0
	Use of pulsed systems	2.0
Computed tomography	Gantry angulation to exclude eye from primary beam (to eye)	2.0 - 4.0
Mammography	Intensifying screens	2.0 - 5.0
	Optimal compression	1.3 - 1.5
	Filtration	3.0

From: NCRP Report No. 100. "Exposure of the U.S. Population from Diagnostic Medical Radiation," page 37.

APPENDIX NO. 14

QUALITY ASSURANCE (QA) AND QUALITY CONTROL (QC) GUIDELINES

QUALITY ASSURANCE (QA)

A. GENERAL QUALITY ASSURANCE (QA) PROVISIONS.

Quality assurance (QA) and quality control (QC) are management tools that include policies and procedures designed to optimize the performance of X-ray facility personnel, and radiographic and ancillary equipment operation. QA includes all of the following:

- o Quality control (QC) of radiographic and ancillary equipment
- o Administration
- o Education of personnel
- o Preventive maintenance methods

Standardized quality control (QC) tests - carried out with care at prescribed intervals, are designed to detect slowly evolving functional X-ray and ancillary equipment abnormalities and to permit corrective action **before** significant deterioration of image quality occurs.

The major reason for a QA program is to optimize diagnosis and therefore the benefits obtained. A QA program warrants the **expenditures** which include:

- o Personnel costs - QA duties include not only performance of QC tests but also initial education and training
- o Test equipment - QC test equipment cost is relatively small in comparison with the total capital outlay of a radiology department
- o Decrease in patient flow from testing - QC tests should be done outside the regular working hours, if possible

The primary **cost savings** of a QA program is the result of a decrease in repeat studies (avoidance of unnecessary radiation dose to the patient). The cost savings also include:

- o Less waste of film
- o Less waste of chemicals
- o Less wear and tear of the equipment
- o Less downtime of equipment
- o Less X-ray personnel time
- o Improvement in patient flow
- o Decreased cost of equipment service

Quality assurance (QA) has four major steps:

- o Acceptance testing
- o Establishment of baseline performance of equipment
- o Diagnosis of changes in equipment performance before they become radiographically apparent
- o Verification of correction of causes of deterioration in equipment performance

B. RETAKE ANALYSIS.

One of the most important goals of a QA program is to decrease the number of radiographs that need to be repeated. Therefore, analysis of the number of retakes done **every three months** is an important part of any QA program. For details regarding this subject consult pages 31 - 43, and Appendix 15, pages 109, 110.

C. QUALITY ASSURANCE (QA) MANUAL.

Each X-ray facility shall have a QA manual that includes at least the following:

1. A list of names and qualifications of individuals responsible for:

    a. Supervision of QA.
    b. Performance of QC tests.
    c. Repairing or servicing X-ray and ancillary equipment.

2. A QA program shall include at least the following:

    a. Brief description of the QC tests to be performed.
    b. Frequency of each QC test.
    c. Limits or parameters of acceptability for each QC test.
    d. A protocol for correcting each QC finding that does not fall within the acceptable limits.
    e. Forms to be used for each QC test.
    f. A list of equipment shall include at least the following:

        (1) Homogeneous phantom.
        (2) Coarse wire mesh contact tool.
        (3) Thermometer (dial, digital or electronic **not** but alcohol or mercury thermometer).
        (4) Sensitometer (blue or green, as appropriate).
        (5) Densitometer.

D. QUALITY ASSURANCE (QA) AND QUALITY CONTROL (QC) RECORDS.

1. Records of all QC tests shall be maintained for X-ray equipment and ancillary equipment, and shall include at least the following:

    a. X-ray equipment performance evaluation, including acceptance testing and radiation safety surveys.
    b. Verification that X-ray equipment is in safe operating order.
    c. Subsequent QC test results.

2. **Records or written logs of maintenance and/or repairs of X-ray equipment shall be kept for at least three years.**

3. All QA and QC records shall be readily available for review by representatives of the Radiologic Health Branch (RHB) or an agency designated by the RHB.

E. FILM PROCESSOR RECORDS.

1. Film processor control charts and control films shall be used to regulate proper processor function, and shall be kept for at least one year.

2. Film processor maintenance logs shall include all of the following records, and these records shall be kept for at least one year:

    a. Preventive maintenance.
    b. Corrective maintenance.
    c. Cleaning and chemistry replacement.

3. Each record entry shall be dated and signed or initialed by the individual who performed the QC test.

F. RECORDS FOR QUALITY CONTROL (QC) TEST EQUIPMENT.

The following records shall be maintained:

1. Evidence that QC test equipment is in good operational order.

2. Evidence of each repair and/or calibration of QC test equipment including at least the following:

   a. Date of repair and/or calibration.
   b. Criteria used in repair and frequency of calibration.
   c. Name of individual who performed the repair and/or calibration.

3. Records of each repair and/or calibration of QC test equipment shall be kept for at least three years.

G. DARKROOM QUALITY ASSURANCE (QA) REQUIREMENTS (General Provisions).

The darkroom QA routine is essential to the production of quality radiographs. These are the rules that must be adhered to:

1. No smoking, eating or drinking in the darkroom.

2. Daily cleaning of the darkroom to keep it free of dust.

3. Daily cleaning of counter tops and processor feed trays.

4. Ascertain that hands are clean and dry before touching film.

5. Ascertain that the darkroom safelight is equipped with an appropriate filter and bulb combination.

6. Keep screens free of artifacts. Screens must be cleaned regularly (not less than monthly) with a screen cleaner recommended by the manufacturer of the screens.

7. Load only one film per cassette.

8. Handle films very carefully (with clean and dry hands, and by the edges only) to prevent artifacts due to static electricity, fingerprints, crinkling, creasing, bending, or scratching.

H. PHOTOGRAPHIC QUALITY CONTROL (QC).

The photographic process controls image quality -- contrast, density, base-plus-fog -- and with it the patient radiation dose. The optical density (O.D.) range should fall within 0.5 to 2.5 O.D. values.

1. Film and Chemical Storage

Test	Test device	Performance criteria	Frequency
Film and chemical storage	Visual inspection; thermometer, hygrometer	Are fumes present? Is radiation present? 65 ± 5°F 50% ± 10% humidity	Monthly

Photographic material should be stored at temperatures less than 24°C (75°F), preferably in the range of 15 to 21°C (60 to 70°F). Open packages of photographic film should be stored in an area with humidity ranging between 40 to 60 percent. Photographic material should not be stored in areas where it can be exposed to chemical fumes or radiation.

Photographic materials are also sensitive to pressure damage; consequently, films should be stored standing on edge, **never flat**.

Photographic chemicals should be stored in similar conditions as the film, that is, standing up. Chemicals should never be allowed to freeze.

2. Darkroom Conditions

Test	Test device	Performance criteria	Frequency
Darkroom conditions	Visual inspection thermometer, hygrometer	Is darkroom clean? 70 ± 5°F 50% ± 10% humidity	Monthly

A major problem encountered in most darkrooms is dust and dirt. Smoking, eating, and drinking should not be allowed in a darkroom. Smoking also produces light that fogs film. Eating may result in particles which can be deposited in cassettes and cause artifacts. When any beverage is spilled on a cassette, the screens will have to be replaced. If the beverage is spilled in the film bin, the cost of replacing the film will be great.

The darkroom should be properly illuminated, that is, film correctly matched with the illumination (usually 7.5 to 15 watt bulb).

The humidity should be maintained between 40 to 60 percent. If the humidity is allowed to drop below 40 percent, an increase in static marks on the film will result. If humidity rises above 60 percent, the films sometimes will become sticky and film handling becomes difficult.

3. Darkroom Fog

Test	Test device	Performance criteria	Frequency
Darkroom fog	Visual inspection, film, cassette, step wedge, opaque material	<0.05 increase in density in 2 minutes	Semiannually

Film fogging must be eliminated because it reduces film contrast in the mid-density range.

Adequate time (15 to 20 minutes) should be spent in the darkroom before testing for darkroom fog to allow for dark adaptation and to allow visual inspection of the darkroom for visible white light (light leaks).

I. AUTOMATIC PROCESSING.

When chemicals are formulated for automatic film processing, the manufacturers assume that a certain number of films of various sizes and of typical radiographic density will be processed daily. The replenishment formulation and rates specified are designed to compensate for:

- o The chemicals exhausted by the development process
- o The oxidation of chemicals
- o The by-products of the development process which are left behind in the developer and fixer tanks

Most automatic processors require processing equivalent to at least 25 (14 x 17-inch) films daily. If this condition is not met then different methods should be used:

- o Flood replenishment
- o Special chemistry
- o Adjustment in replenishment rates

J. PROCESSOR QUALITY CONTROL (QC).

The best means of processor QC is to process a freshly exposed sensitometric strip and read the strip with a densitometer.

The objective of processor QC is to test the processor and chemicals with the same film normally used in the processor.

NOTE: The sensitometric strips should be exposed to sensitometric light only, not directly to X-rays.

Control charts are the key to the photographic QC program, since they allow for the perception of trends, both slow and rapid changes, in the areas being monitored.

Processor QC program should monitor the following:

- o **Base-plus-fog density**
- o **Mid-density [usually around 1.0 optical density (O.D.) above the base-plus-fog level]**
- o **Density difference [usually measured between 0.25 and 2.50 optical density (O.D.) above the base-plus-fog level]**

4. Processor Sensitometric Evaluation

Test	Test device	Performance criteria (reproducibility)	Frequency
Processor sensitometric evaluation	Sensitometer, densitometer, control emulsion	Base + fog $\pm$ 0.05 Mid-density $\pm$ 0.10 Density difference $\pm$ 0.10	Daily - before processing patient films

Process a freshly exposed sensitometric strip and read that strip with a densitometer.

Processor QC should be carried out at the **beginning of each day**, after sufficient time has elapsed for the developer temperature to reach its operating level and all systems have stabilized.

5. Tank Level Check, Clean-up Films, Cleaning of Crossover Rollers

Test	Test device	Performance criteria	Frequency
Tank level checks, clean-up films, clean crossover rollers	Visual inspection, clean-up films	Full tanks, no scratches on films, are crossover rollers clean?	Daily

At the end of the work day the cross-over rollers should be removed, cleaned with warm water and a damp, soft cloth, and dried. The cover of the processor should be left open about 5 cm (2 inches) so that moisture and chemical fumes do not accumulate and cause corrosion.

6. Cleaning and Preventive Maintenance

Test	Test device	Performance criteria	Frequency
Cleaning and preventive maintenance	As suggested by manufacturer	As indicated by manufacturer	Follow manufacturer's requirements

7. Developer Replenishment Rate

Test	Test device	Performance criteria	Frequency
Replenishment rate	Visual inspection	± 5%	Daily

The replenishment rates should be those suggested by the film manufacturer or as required by workload.

8. Fixer Replenishment Rate

Test	Test device	Performance criteria	Frequency
Fixer replenishment rate	Visual inspection	± 5%	Daily

Fixer solutions should be changed regularly, whenever developer solutions are changed. Fixer tanks and racks should be cleaned at that time.

The pH or silver concentration should be monitored as an indicator of fixer activity. It should be noted that it is impossible to overreplenish fixer; however, in order to optimize the cost, the amount of fixer replenished or added should be as specified by the manufacturer.

9. Fixer Flow Meter Accuracy

Test	Test device	Performance criteria	Frequency
Fixer flow meter accuracy	Stop watch and graduated cylinder	± 5%	Semiannually

Check fixer replenishment rates daily using the built-in flow meter, if so equipped; otherwise use a graduated cylinder.

10. Film Washing Time

Test	Test device	Performance criteria	Frequency
Film washing	Visual inspection of water flow meter	± 10%	Daily

A useful tool in ensuring adequate film washing is a flow meter on the water line feeding the processor. The flow meter should be visually inspected daily to ensure adequate water flow. An in-line water filter may be necessary if the water supply contains particulate matter.

11. Film Fixer Retention

Test	Test device	Performance criteria	Frequency
Film fixer retention	Fixer retention test kit	Less than 2 $\mu g/cm^2$ retained thiosulfate	Semiannually

Films should be adequately washed and finished radiographs should be stored at 21° C (70° F) and 40 - 60% humidity. There are tests for fixer retention. Most kits require that a few drops of the test solution be applied to one emulsion (of dual emulsion films) so that the resulting stain be compared with a standard sample. For archival storage, less than 2 $\mu g/cm^2$ thiosulfate ion (fixer) should remain in the film after washing.

12. Processor Transport Time

Test	Test device	Performance criteria	Frequency
Processor transport time	Stop watch	± 3%	Annually

Automatic processors have more or less fixed transport speeds or times. These speeds or times can be changed internally if necessary.

Even small changes in transport time can significantly affect the development time. **The total developer immersion time is only 20 seconds for a 90-second processor.**

The processor transport time is measured, using a stop watch, from the instant the leading edge of the film enters the entrance roller until the leading edge exits the last set of rollers in the drier section of the processor.

13. Developer Temperature

Test	Test device	Performance criteria	Frequency
Developer temperature	Thermometer built into processor	± 0.5°F	Daily

The developer temperature should be as recommended by the manufacturer for the specific film-developer combination being used and should be maintained within ± 0.3°C (± 0.5°F).

NOTE: Never use mercury or alcohol thermometers because they may break and contaminate processing solutions.

14. Built-in Developer Thermometer Accuracy

Test	Test device	Performance criteria	Frequency
Built-in developer thermometer accuracy	Calibrated thermometer	± 0.5°F	Monthly

The accuracy of the built-in thermometer should be checked at least monthly with a calibrated thermometer..

15. Wash Water Temperature

Test	Test device	Performance criteria	Frequency
Wash water temperature	Thermometer built into processor	± 5.0°F	Daily

An in-line thermometer should be available to monitor the wash-water temperature.

16. Developer Recirculation Filter

Test	Test device	Performance criteria	Frequency
Developer recirculation filter	As suggested by manufacturer	As indicated by manufacturer	Follow manufacturer's requirements

Every processor should also contain a filter in the developer recirculating system. This filter should be changed as suggested by the manufacturer.

17. Water Filters

Test	Test device	Performance criteria	Frequency
Water filters	Visual inspection of flow meter	Change when flow rate decreases by more than 10%	Daily

It is usually necessary to install water filters in the wash-water supply line to prevent built-up of particulates in the wash-water tank and the imbedding of this material in the emulsion of the film. These filters should not allow particles larger than 25 microns to pass. Filters should be changed frequently as suggested by the manufacturer.

18. Water Flow Meter Accuracy

Test	Test device	Performance criteria	Frequency
Flow meter accuracy	Stop watch and graduated cylinder	± 5%	Quarterly

A water-flow meter should be provided at the point where the water enters the processor. The replenishment flow meter should be calibrated when the processor is installed and the calibration should be checked quarterly.

19. Daylight Systems

Test	Test device	Performance criteria	Frequency
Daylight systems	As suggested by manufacturer	As indicated by manufacturer	Follow manufacturer's requirements

Preventive maintenance is the major tool of quality control for daylight systems. During systems use, all of the following should be checked and reported:

- o Light leaks
- o Film artifacts
- o Improper loading of cassettes
- o Improper unloading of cassettes
- o Accuracy of the time and date portions of the automatic identification systems

20. Processor Stand-by Units

Test	Test device	Performance criteria	Frequency
Processor stand-by units (verify function)	Visual inspection	As indicated by manufacturer	Daily

When films are not being processed frequently, the stand-by unit places the processor in the stand-by mode, which usually turns off the drive system and reduces the water flow rate while maintaining the chemicals and film dryer at the correct temperatures.

21. Automatic Chemical Mix System

Test	Test device	Performance criteria	Frequency
Automatic chemical mix system	As suggested by manufacturer	As indicated by manufacturer	Follow manufacturer's requirements

Auto mix systems, though convenient from the mixing point of view, are harder to clean and maintain than replenishment tanks.

22. Silver Recovery Efficiency

Test	Test device	Performance criteria	Frequency
Silver recovery efficiency	Silver test paper, direct reading device	+ 10% of estimated weight	Quarterly

Silver recovery systems must meet environmental protection laws and regulations. Specifically, processing less than 500 gallons per month of silver-containing photographic solutions qualifies a generator to be conditionally exempt if the waste is: (1) hazardous only for silver, (2) treated on-site within 90 days, and (3) the silver concentration is reduced to a level less than 5 milligrams per liter (mg/l).

Processing between 500 and 5000 gallons per month per unit of silver-containing photographic solution qualifies a generator to be conditionally authorized. Processing more than 5000 gallons per month in a unit requires operation under "Permit-By-Rule" (PBR).

For further information regarding processing solution disposal contact:

Department of Toxic Substances Control
Onsite Hazardous Waste Treatment Unit
400 P Street, 4th Floor
P.O. Box 806
Sacramento, CA 95812-0806
(916) 324-2423

K. QUALITY CONTROL (QC) IN CONVENTIONAL RADIOGRAPHY.

Conventional radiographic systems have many elements, each of which is subject to variability or to change with time. The more important elements in this system are:

- Kilovoltage (kVp)
- Milliamperage (mA)
- Exposure time
- X-ray beam filtration
- Collimation (X-ray beam restriction)
- Focal spot size
- Grid (type, uniformity, and alignment)
- Intensifying screens
- Cassettes
- Radiographic/X-ray film
- Darkroom conditions
- Photographic processor and chemicals

Each of the elements in the system can drift or degrade such that the image quality may be degraded. Therefore, in order to carry out all operations in a cost effective manner, it is essential to measure and control all of the appropriate variables in the radiographic imaging chain.

The appropriate QC tests shall be performed, after the repair and/or replacement of any component of the X-ray system, prior to using the equipment on human beings if such repair and/or replacement may affect the following:

- Image quality
- Phototimer reproducibility
- Exposure timer accuracy
- Milliampere-seconds (mAs) linearity
- Kilovolt peak (kVp) accuracy
- Skin entrance radiation dose
- Focal spot size

L. X-RAY TUBES AND COLLIMATORS.

23. Filtration (Half-Value Layer – HVL)

Test	Test device	Performance criteria	Frequency
Filtration (HVL)	Dosimeter, type 1100 aluminum sheets, semi-log paper	See page 11	Annually

Since it is not possible to visually verify the amount of inherent filtration in the X-ray beam, it is necessary to measure the half-value layer (HVL) of the X-ray beam. The half-value layer must conform to the regulatory requirements of section 30308 (a) (3) - see page 11.

24. Light Field and X-ray Field Alignment

Test	Test device	Performance criteria	Frequency
Light field and X-ray field alignment	Alignment template or nine pennies image and tape measure	± 2% of source-to-distance	Semiannually

The center of the X-ray field must be aligned to the center of the image receptor to within ± 2 percent of the source-image-distance (SID) and the SID indicator must be accurate to within ± 2 percent. The alignment of the center to the field is not the only concern - the edges must also be accurate to within ± 2 percent.

25. X-ray Beam, Bucky Motion and Centering

Test	Test device	Performance criteria	Frequency
X-ray beam bucky motion and centering	Homogeneous phantom and lead strips	Lead strips should be centered. Density uniform to ± 0.10 O.D. perpendicular to anode-cathode axis	Annually

The X-ray beam must be perpendicular to the bucky grid and must be centered to the X-ray film to obtain uniform density over the film. The grid motion must be uniform.

26. X-ray Beam Perpendicularity, and SID Indicator Accuracy

Test	Test device	Performance criteria	Frequency
X-ray beam, perpendicularity SID indicator accuracy	Perpendicularity test tool and tape measure	Perpendicularity accuracy provided by tool manufacturer. SID indicator should be within ± 2% of measured value	Annually

Use a test tool that measures directly the X-ray central ray (CR) perpendicularity.

27. Focal Spot Size

Test	Test device	Performance criteria	Frequency
Focal spot size	Lead star pattern, slit assembly, or pinhole camera	See Appendix 16, page 111	Annually

The determination of focal spot size should follow the standard outlined in "Measurement of Dimensions and Properties of Focal Spots of Diagnostic X-Ray Tubes," the National Electrical Manufacturer's Association, 1990, Publication NEMA XR-5, except that acceptance testing for microfocal spot size should be made with a 10 micron slit assembly.

28. Kilovoltage (kVp) Accuracy

Test	Test device	Performance criteria	Frequency
kVp	direct reading kVp device	± 5%; less over limited range, e.g. ± 2 kVp for 60 to 100 kVp	Annually

The actual (measured) vs. indicated kVp shall be maintained as specified.

29. Exposure Timer Accuracy

Test	Test device	Performance criteria	Frequency
Exposure timer	Timing device	Three phase ± 5% Single phase ± 10%	Annually

The exposure timer/phototimer control must be checked for reproducibility. The coefficient of variation of exposures shall not be greater that ± 5 percent as measured on 4 - 6 consecutive exposures at a commonly used setting.

30. Gy/mAs (formerly mR/mAs)

Test	Test device	Performance criteria	Frequency
Gy/mAs	Dosimeter, homogeneous phantom	± 10%	Annually

The assessment technique requires measurement of the X-ray exposure at a fixed kVp and mAs, and under set geometrical conditions.

31. mAs Linearity Reproducibility

Test	Test device	Performance criteria	Frequency
Linearity	Dosimeter	± 10% over clinical range	Annually

The average ratios of radiation dose to the indicated milliampere-seconds product rads/mAs obtained at any two consecutive tube current settings shall not differ by more than 0.10 times their sum. That is, maximum reading minus minimum reading divided by maximum reading divided by minimum readings shall be less than 10 percent.

32. Radiation Dose Reproducibility

Test	Test device	Performance criteria	Frequency
Radiation dose (formerly exposure) reproducibility	Dosimeter	± 5%	Annually

Reproducibility means that the kVp, mA, and exposure time can be changed, the original technique reset, and the radiation dose will be similar (within ± 5 percent) to the originally measured radiation dose. A minimum of three exposure measurements should be made and the average and range determined.

M. PHOTOTIMERS.

For a phototimer (automatic exposure control device) to function properly, the technologist must:

- o Ascertain that the X-ray generator is properly calibrated
- o Select the proper phototimer sensor panel
- o Position patient correctly (over the appropriate phototimer sensor panel)
- o Ensure that the phototimer circuits are properly calibrated for the specified intensifying screen being used
- o Ascertain that the part to be examined covers the entire chamber
- o Ascertain that the exposure time does not result in decreased film sensitivity due to reciprocity failure of the film

33. Phototimer Reproducibility

Test	Test device	Performance criteria	Frequency
Phototimer reproducibility	Homogeneous phantom and densitometer	Film densities within ± 0.15 of average for all rooms	Annually

The density of all patient-equivalent-phantom films produced by different units should be within ±10 percent of the average density of all the films.

34. Radiation Dose Per Film

Test	Test device	Performance criteria	Frequency
Radiation dose (formerly exposure) per film	Homogeneous phantom and densitometer	Film density of 1.20 ± 0.15 for AP lumbar spine technique and appropriate phantom	Annually

The staff should be aware of the amount of radiation which a typical patient would receive for each common radiographic projection used.

N. ACCESSORIES.

35. Screen/Film Contact

Test	Test device	Performance criteria	Frequency
Screen/film contact	Coarse copper mesh	Visual inspection - no areas of poor contact/blurring	Semiannually

Film/screen contact shall be verified by use of a coarse wire mesh test tool across the entire film/screen surface.

36. Grid Uniformity/Bucky Grids/Grid Cassettes/Clip-on Grids

Test	Test device	Performance criteria	Frequency
Grid uniformity bucky grids, grid cassettes, clip-on grids	Homogeneous phantom	Uniform films, no grid lines, density of 1.20 $\pm$ 0.10 O.D. perpendicular to anode-cathode axis	Annually

The grid uniformity can best be evaluated by producing a radiograph of a homogeneous phantom at a clinical kVp and at an exposure that produces a density of approximately 1.20 on the film.

37. Grid Alignment

Test	Test device	Performance criteria	Frequency
Grid alignment	Homogeneous phantom	Uniform films, density of 1.0 $\pm$ 0.10 O.D. perpendicular to anode-cathode axis	Annually

The film produced for testing grid uniformity can also be used to assist in evaluating grid alignment.

38. Screen/Film/Cassette Speed Matching

Test	Test device	Performance criteria	Frequency
Screen/film/ cassette speed matching	Standard (comparison) cassette	Densities within $\pm$ 0.05 O.D. for all cassettes used in one area	Annually

There are two problems in screen/film/cassette speed matching:

- Matching the spectral characteristics of the light emitted by intensifying screens to the spectral sensitivity of the film
- Matching screen/film/cassette combinations based on screen type and age, and cassette type and age in order to minimize variations in film density

Blue-light-emitting screens should not be used with green-sensitive film and vice versa.

SUMMARY

PARAMETERS TO BE TESTED FOR X-RAY EQUIPMENT QUALITY CONTROL (QC)

A. Photographic QC.

Test	Frequency	Test device	Performed by	Page
Film and chemical storage	Monthly	Visual inspection thermometer, hygrometer	QA personnel	94
Darkroom conditions	Monthly	Visual inspection thermometer, hygrometer	QA personnel	95
Darkroom fog	Semiannually	Visual inspection film, cassette, step wedge, opaque material	QA personnel	95
Retake rate analysis	Quarterly	Calculation based on number of rejected films	QA personnel	92

B. Automatic Processing QC.

Processor sensitometric evaluation	Daily	Densitometer, sensitometer, thermometer, control emulsion	QA personnel	95
Tank level check, clean-up films, clean cross-overs	Daily	Visual inspection No scratches on film Clean cross-overs	QA personnel	97
Cleaning and preventive maintenance	As suggested by manufacturer	Follow manufacturer's requirements	QA personnel	97
Developer replenishment rate	Daily	Visual inspection	QA personnel	97
Fixer replenishment rate	Daily	Visual inspection	QA personnel	97
Fixer flow meter accuracy	Semiannually	Stop watch, graduated cylinder	QA personnel	97
Film washing time	Daily	Visual inspection of water flow meter	QA personnel	98
Film fixer retention	Semiannually	Fixer retention test kit	QA personnel	98

B. Automatic Processing QC (continued).

Test	Frequency	Test device	Performed by	Page
Processor transport time	Annually	Stop watch	QA personnel	98
Developer temperature	Daily	Thermometer built into processor	QA personnel	98
Built-in developer thermometer accuracy	Monthly	Calibrated thermometer	QA personnel	99
Water wash temperature	Daily	Thermometer built into processor	QA personnel	99
Developer recirculation filter	As suggested by manufacturer	Follow manufacturer's requirements	QA personnel	99
Water filters	Daily	Visual inspection of flow meter	QA personnel	99
Water flow meter accuracy	Quarterly	Stop watch, graduated cylinder	QA personnel	99
Daylight systems	As suggested by manufacturer	Follow manufacturer's requirements	QA personnel	100
Processor stand-by units (verify function)	Daily	Visual inspection	QA personnel	100
Automatic chemical mix system	As suggested by manufacturer	Follow manufacturer's requirements	QA personnel	100
Silver recovery efficiency	Quarterly	Silver test paper, direct reading device	QA personnel	100

C. QC in Conventional Radiography.

Filtration (Half-value layer)	Annually	Aluminum HVL set with ion chamber	Physicist	102
Light field/X-ray field alignment	Semiannually	Alignment template or nine pennies and tape measure	QA personnel	102
X-ray beam, bucky motion and centering	Annually	Homogeneous phantom, lead strips	QA personnel	102

C. QC in Conventional Radiography (continued).

Test	Frequency	Test device	Performed by	Page
X-ray beam perpendicularity SID accuracy	Annually	Perpendicularity test tool and tape measure	QA personnel	102
Focal spot size	Annually	Star pattern test tool	Physicist	103
kVp accuracy	Annually	kVp meter or cassette	Physicist	103
Exposure timer accuracy	Annually	Digital timer	Physicist	103
Grays/ mAs	Annually	Dosimeter, homogeneous phantom	Physicist	103
mAs linearity reproducibility	Annually	Ion chamber or digital timer	Physicist	103
Radiation dose reproducibility	Annually	Dosimeter	Physicist	104
Phototimer reproducibility	Annually	Phantom and ion chamber	Physicist	104
Radiation dose per film	Annually	TLD or ion chamber measurements	Physicist	104

D. Accessories QC.

Screen/film contact	Semiannually	Coarse copper mesh	QA personnel	105
Grid uniformity	Annually	Homogeneous phantom	QA personnel	105
Grid alignment	Annually	Homogeneous phantom	QA personnel	105
Screen/film and cassette matching	Annually	Standard (comparison) cassette	QA personnel	105

NOTE: QA personnel includes all of the following:

- Specially trained radiologic technologists
- Radiological engineers
- Specially trained X-ray equipment and accessory maintenance personnel
- Health physicist or medical physicist

APPENDIX NO. 15A

REPEAT FILM ASSESSMENT FORM

Facility _____ Date _____

Patient Condition: A - ambulatory; B - wheelchair; C-stretcher

Reasons for Repeating:

1. Overexposure
2. Respiratory motion
3. Positioning error
4. Processing error
5. Film/beam alignment
6. Underexposed
7. Motion (not respiratory)
8. Multiple exposures
9. Foreign object
10. Screen error
11. Grid error
12. Other (specify)

Room No.	Patient			Examination		Films Retaken	
	Age	Sex	Condition	Type of film	# of Films	Project retaken	Reason

APPENDIX NO. 15A

REPEAT FILM ASSESSMENT FORM

Facility _____ From _____ To_____

C a u s e	Number of films	Percentage of rejects	Percentage of repeats
1. Overexposed			
2. Respiratory motion			
3. Positioning errors			
4. Processing errors			
5. Film-beam alignment			
6. Underexposed			
7. Motion (not respiratory)			
8. Multiple exposures			
9. Foreign object			
10. Screen errors			
11. Grid errors			
12. Other			
13. Other			
14. Other			
15. Quality control films		xxxxxxxxxxxxxxxxxxxxx xxxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxxxxxxxx xxxxxxxxxxxxxxxxxxxxx

TOTALS:

Total Waste (1-15): Number: Percentage:

Total Rejects:

Total Repeats:

Total Film Used:

Name of Individual who conducted the assessment: _____

APPENDIX NO. 16

FOCAL SPOT SIZE ACCEPTABLE LIMITS (NEMA, 1984)

Nominal size (mm)	Minimum focal spot dimensions	
	Width (mm)	Length (mm)
0.05	0.0075	0.0075
0.10	0.15	0.15
0.15	0.23	0.23
0.20	0.30	0.30
0.25	0.40	0.40
0.30	0.45	0.65
0.40	0.60	0.85
0.50	0.75	1.10
0.60	0.90	1.30
0.70	1.10	1.50
0.80	1.20	1.60
0.90	1.30	1.80
1.00	1.40	2.00
1.10	1.50	2.20
1.20	1.70	2.40
1.30	1.80	2.60
1.40	1.90	2.80
1.50	2.00	3.00
1.60	2.10	3.10
1.70	2.20	3.20
1.80	2.30	3.30
1.90	2.40	3.50
2.00	2.60	3.70

Definitions:

Nominal focal spot is the manufacturer's stated anode target size.

Measured focal spot is the projected focal size measured along the central axis of the X-ray tube at the image receptor.

Effective focal spot is the length and width of the X-ray beam as projected down the central axis of the X-ray tube.

Actual focal spot is the actual area on the anode that is struck by the X-ray beam.

APPENDIX NO. 17

SUMMARY OF STATE BUILDING CODE REGARDING STRUCTURAL SHIELDING

Excerpts from: "Part 12, Title 24, State Referenced Standards Code, California Code of Regulations".

Chapter 12-91 -- Radiation Shielding Standards.

Section 12-91-101 -- All Healing Arts X-Ray Installations.

All radiation shielding barriers in rooms and enclosures housing radiation machines shall comply with the mandatory standards and appendices in Report No. 35, "Dental X-RAY Protection"; Report No. 49, "Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma Rays of Energies up to 10 MeV"; Report No. 51, "Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities". Published by the National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Bethesda, Maryland 20814.

Section 2-9102 -- Scope.

For the purposes of this chapter, the following terms shall have the meaning indicated:

Primary Protective Barrier -- A barrier to attenuate the useful beam.

Secondary Protective Barrier -- A barrier to attenuate stray radiation.

Useful Beam -- The radiation which passes through the window, aperture, cone, or other collimating device of the tube housing.

Stray Radiation -- Radiation not serving any useful purpose, which includes leakage and secondary radiation.

Section 2-9103 -- Radiation Shielding Barriers.

All radiation shielding barriers in rooms and enclosures housing machines shall meet the requirements of Section 12-1-101, Chapter 12-91, Part 12, State Referenced Standards Code. The Department of Health Services is the only agency that may grant a variance or exemption to these standards.

Section 2-9104 -- Medical Radiographic and Photofluorographic Installations.

(a) **Operator Station.** The operator's station at the control shall be behind a protective barrier either in a separate room, in a protective booth, or behind a shield which will intercept the useful beam and any radiation which has been scattered only once.

(b) **Patient Observation and Communication.** Provisions shall be made for the operator to observe and communicate with the patient without leaving the shielded position at the control panel. When an observation window is used, it must provide radiation attenuation equal to that required in the surrounding barrier.

APPENDIX NO. 18

EXCERPTS FROM TITLE 22, CALIFORNIA CODE OF REGULATIONS (Health Facilities and Referral Agencies)

Section 70251. Radiological Services Definition.

Radiological services means the use of X-ray, other external ionizing radiation, and/or thermography, and/or ultrasound in the detection, diagnosis and treatment of human illnesses and injuries with appropriate staff, space, equipment and supplies. Ultrasound although properly the province of physical medicine, may be considered part of the radiological services.

Section 70253. Radiological Services General Requirements.

(a) All hospitals shall maintain diagnostic radiological services.

(b) Written policies and procedures shall be developed and maintained by the person responsible for the service in consultation with other appropriate health professionals and administration. Policies shall be approved by the governing body. Procedures shall be approved by the administration and medical staff where such is appropriate.

(c) The responsibility and the accountability of the radiological services to the medical staff and administration shall be defined.

(d) The use, storage and shielding of all radiation machines and radioactive materials shall comply with the California Radiation Control Regulations, Subchapter 4, Chapter 5, Title 17, California Code of Regulations.

(e) All persons operating or supervising the operation of X-ray machines shall comply with the requirements of the Regulations Relating to Radiologic Technology, Subchapter 4.5, Chapter 5, Title 17, California Code of Regulations.

(f) Diagnostic radiological services may be performed on the order of a person lawfully authorized to give such an order.

(g) Reports of radiological service examinations shall be filed in the patient's medical record and maintained in the radiology unit (department).

(h) X-ray films, or reproductions thereof, shall be retained for the same period of time as is required for other parts of the patient's medical record.

(i) Periodically, an appropriate committee of the medical staff shall evaluate the services provided and make recommendations to the executive committee of the medical staff and administration.

Section 70255. Radiological Service Staff.

(a) A physician shall have overall responsibility for the radiological service. This physician shall be certified or eligible for certification by the American Board of Radiology. If such a radiologist is not available on a full-time or regular part-time basis, a physician, with training and experience in radiology, may administer the service. In this circumstance, a radiologist, qualified as above, shall provide consultation service at suitable intervals to assure high quality service.

(b) Sufficient certified radiologic technologists shall be employed to meet the needs of the service being offered.

(c) There shall be at least one person on duty or on call at all times capable of operating radiological equipment.

Section 70257. Radiological Service Equipment and Supplies.

(a) There shall be sufficient equipment and supplies maintained to adequately perform the radiological services that are offered in the hospital. As a minimum, the following equipment shall be available.

(1) At least one radiographic and fluoroscopic unit. On and after January 1, 1977, fluoroscopic units shall be equipped with image intensifiers.

(2) Film processing equipment.

(b) Proper resuscitative and monitoring equipment shall be immediately available.

Section 70259. Radiological Service Space.

(a) There shall be sufficient space maintained to adequately provide radiological services. This shall include but not be limited to the following:

(1) A separate X-ray room large enough to accommodate the necessary radiographic equipment and to allow easy maneuverability of stretchers and wheelchairs.

(2) Toilet facilities located adjacent to or in the immediate vicinity.

(3) Dressing room facilities for patients.

(4) Film processing area.

(5) Sufficient storage space for all the necessary X-ray equipment, supplies and for exposed X-ray film and copies of reports.

(6) If X-ray examinations are to be performed on outpatients, outpatient access to the radiological spaces shall not traverse a nursing unit.

APPENDIX NO. 19

GLOSSARY

NOTE: 1. 10 CFR 20 refers to the Nuclear Regulatory Commission Regulations incorporated by reference in the California Code of Regulations (CCR), title 17.

2. Sections 30xxx refer to the California Code of Regulations (CCR), title 17.

Absorbed Dose: Means the energy imparted by ionizing radiation per unit mass of irradiated material. The unit of absorbed dose are the rad and the gray (Gy). See also dose. **10 CFR 20**

Absorption (differential, rare-earth screen, specific rate of, visible light): The transfer of energy from an X-ray beam to the atoms or molecules of the matter through which it passes. The process whereby radiation is stopped and reduced in intensity as it passes through matter. Lead, which is denser than most materials, is one of the best absorbers of X-rays.

Adult: Means an individual 18 or more years of age. **10 CFR 20**

ALARA: Acronym for "as low as is reasonably achievable" means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest. **10 CFR 20**

Aluminum Equivalent: The thickness of type 1100 aluminum alloy affording the same attenuation, under specified conditions, as the material in question.

Ambient: The natural or inherent environment in which some event or activity is to take place. For example, ambient lighting would refer to the normal level of illumination in a particular area.

Ampere: The unit of electrical current equal to the steady current produced by one volt applied across a resistance of one ohm. This electrical current determines the quantity of X-rays produced at the anode (target) of the X-ray tube.

Anode: A positive electrode, also referred to as the target, toward which electrons are accelerated from the cathode. The target is usually composed of tungsten. When these electrons hit the anode or target some of their kinetic energy is converted to X-rays.

Aperture: (For computed tomography) - The opening in the collimation that allows radiation to reach the detector.

Artifact: Any density or mark on a radiograph that is caused by something not belonging to the part being X-rayed.

Attenuation: The process by which an X-ray beam of radiation is reduced in intensity by absorption or scattering when passing through material (see absorption).

Attenuation Block: A block or stack of material with a cross section larger than the beam with a total thickness equivalent to 3.8 cm of type 1100 aluminum.

Automatic Exposure Control: Means a device which automatically controls one or more technical factors in order to obtain at a prescribed location(s) a required quantity of radiation. 30306(a)

Base Density: The optical density of a film is the optical density that would result if an unexposed film were processed through the fixer, wash, and dryer, without first passing through the developer. The optical density is due to the supporting base of the film alone.

Base Plus Fog Density: The optical density of a film due to its base density plus any action of the developer on the unexposed silver halide crystals. The base plus fog density can be measured by passing an unexposed film through the entire processing cycle and measuring the resultant optical density with a densitometer.

Beam: A flow of electromagnetic radiation. See useful beam.

Beam Limiting/Defining Device: A device which provides a means to restrict the dimensions of the useful beam. In regions outside the beam the device, if an integral part of the radiation-producing equipment, shall provide shielding adequate to meet the leakage requirements of the source assembly to which it is attached.

Bergonié and Tribondeau, Law of: The empirical rule which states that the radiosensitivity of tissues depends on the number of undifferentiated cells which the tissue contains, the degree of mitotic activity in the tissue, and the length of time the cells of the tissue stay in active proliferation. Generally, the more undifferentiated the cell line, the greater the radiosensitivity.

Bone Marrow: A soft tissue which constitutes the central filling of many bones and serves as a producer of red blood cells. Bone marrow is especially sensitive to X-rays.

Bucky: See grid.

Calipers: An instrument used to measure patient thickness. The measurement should be done where the central ray (CR) enters and exits the body part.

Carcinogenic: Producing cancer.

Cassette: A light-tight film holder containing intensifying screens mounted within front and back structures which are hinged together and which are made of low X-ray absorption material.

Cataract: A clouding of the crystalline lens of the eye which obstructs the passage of light.

Cathode: A negative electrode; electrode in the X-ray tube from which electrons are emitted. It consists of one or two filaments and a focusing cup.

Centigray: 0.01 gray. 1cGy equals one rad.

Central Ray (CR or central beam): Refers to the X-rays in the center of the useful or primary beam.

Certified Source Assembly: A source assembly certified by an assembler to comply with the leakage requirements of the Radiation Control for Health and Safety Act of 1968 (FDA, 1968).

Chamber, Pocket Ion: A small, pocket-sized ionization chamber used for monitoring radiation exposure of personnel. Before use it is given a charge and the amount of discharge during the period of use is a measure of the total radiation exposure during the period.

Characteristic Curve: A type of input-output curve used to express the change in density with the change in radiation dose of the photographic or X-ray film. Also sometimes known as an H & D curve. The characteristic curve graphically demonstrates the relationship between photographic density and radiation dose. In technical terms: Characteristic curve is a graph of photographic density against logarithm of radiation dose.

Chromosome: Important macromolecule found in all body cells. Chromosomes contain the genes or heredity-determining units.

Chronic Exposure: Irradiation which is spread out over a period of years.

Cine Camera: A camera used for recording motion - in cinefluoroscopy one which usually visualizes either 16 or 35 mm film. Frame rates may be on the order of 15 to 60 frames per second.

Cineradiography: Means the making of a motion picture record of the successive images appearing on a fluorescent screen. **30306(b)**

Collimator: A device for restricting/confining/limiting a beam of radiation within an assigned solid angle.

Compliance Test: A compliance test is performed on X-ray equipment to ensure that the X-ray unit meets the radiation safety regulations.

Compton Effect or Scattering: An interaction between an incoming X-ray photon and an outer shell electron of an atom of the irradiated object in which the photon surrenders a portion of its kinetic energy to dislodge the electron from its orbit and then continues on its way but in a new direction. This process accounts for most of the scattered radiation produced during diagnostic X-ray examinations.

Computed Tomography (CT): See tomography.

Cone: A round/circular metal tube/shield attached to the X-ray tube housing or placed in front of the X-ray tube to limit the size of the X-ray beam to a predetermined size and shape.

Cones: One of the two types of cells contained in the retina of the human eye. Cones are less sensitive than are the rods, but are responsible for creating color differences.

Contact Therapy: Means irradiation of accessible lesions usually employing a very short source-skin distance and potentials of 40-50 kV. **30306 (c)**

Contrast: In radiology, contrast is defined as the difference in density between light and dark areas on the processed film. Contrast can be measured from a characteristic or H & D curve by finding the tangent of the straight line portion of the curve.

Contrast Agents or Media: Low toxicity materials such as barium or iodine which possess high atomic numbers and thus decrease the transmission of X-rays. The absorption of X-rays in barium and iodine is much greater than that in bone and tissue which have much lower effective atomic numbers. The use of contrast agents in diagnostic radiology is derived from their ability to enhance the photoelectric effect.

Control Chart: A chart used to record and control the performance of a radiographic processor as a function of time.

Controlled Area: Means an area, outside of a restricted area but inside the site boundary, access to which can be limited by the licensee for any reason. **10 CFR 20** (It is an area in which radiation safety rules are enforced.)

Coulomb: Means a unit of electric charge equal to 1 ampere-second (the quantity of electricity transferred by a current of one ampere in one second).

Dead-man Switch: Means a switch so constructed that a circuit-closing contact can only be maintained by continuous pressure by the operator. **30306(d)**

Declared Pregnant Woman: Means a woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception. **10 CFR 20**

Deep-Dose Equivalent (H_d): Applies to external whole-body exposure and is the dose equivalent in a tissue depth of 1 cm (1000 mg/cm^2). **10 CFR 20**

Definition: See detail.

Densitometer: An instrument used to measure film density which is the degree of blackening of film by measuring the ratio of the light intensity incident on the film to the light intensity transmitted by the film. (The densitometer is a device designed to measure the optical density of an exposed and processed film. It measures the density of the individual steps on films exposed in a sensitometer, and is commonly used for daily processor quality control.)

Density: Film blackening or the amount of light transmitted through the film. (The density on a radiograph is related to the amount of silver deposited on the film base.)

Department: Means the State Department of Health Services. **30301 (c)**

Detail (definition): In radiography, detail refers to the sharpness of structure lines or contour lines on the processed film.

Developer: The chemical solution (alkaline) used in film processing that makes the latent image visible.

Developer Replenishment: The purpose of developer replenishment is to maintain the proper alkalinity, chemical activity, and level of solution in the developer tank.

Diagnostic Source Assembly: A diagnostic source housing (X-ray tube housing) assembly with a beam limiting device attached. This assembly shall be so constructed that the leakage radiation air kerma measured at a distance of one meter from the source does not exceed 1 mGy (0.1 rad) in one hour when the source is operated at its leakage technique factors.

Diagnostic-Type Tube Housing: Means an X-ray tube housing constructed so that the leakage radiation measured at a distance of 1 meter from the source cannot exceed 100 millirads in 1 hour when the tube is operated at its maximum continuous rate of current for the maximum rated tube potential. **30306(e)**

Diaphragm: A plate, usually lead, with a central aperture so placed as to restrict the useful X-ray beam. See collimator.

Digital Radiography: A diagnostic procedure using an appropriate radiation source and an imaging system which collects, processes, stores, recalls and presents image information in a digital rather than analog fashion.

Direct Effect: The effect of ionizing particles interacting directly with (transferring their energy to) biologic macromolecules such as DNA, RNA, ATP, proteins or enzymes: the chemical bonds of these macromolecules break and they become abnormal structures.

Distortion: Unequal magnification of different portions of body area being X-rayed.

Dominant Mutation: A genetic mutation which will probably be expressed in the offspring.

Dose or Radiation Dose: Is a generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, or total effective dose equivalent, as defined in other paragraphs of this section. **10 CFR 20**

> **Absorbed Dose:** The amount of energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad (1 rad equals 100 ergs per gram) (see rad) and the gray (Gy). The SI unit of absorbed dose is the gray (Gy); 1 Gy = 1 joule/kg. There are 100 rads per Gy.
>
> **Dose Equivalent (H_T):** Means the product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert (Sv) (1 rem = 0.01 Sv). **10 CFR 20**
>
> **Gonad Dose:** The amount of radiation absorbed by the gonads resulting from any part of the body being exposed to X-rays.
>
> **Dose Rate:** Absorbed dose (or dose equivalent) delivered per unit of time.

Dosimeter: An instrument used to detect and measure accumulated radiation exposure.

> **Personnel Dosimeters:** Devices designed to be worn or carried by an individual for the purpose of determining the dose equivalent received (e.g., film badges, pocket chambers, pocket dosimeters, ring badges, thermoluminescent dosimeters, etc.).
>
> **Personnel Dosimetry:** The use of instruments and associated procedures (including calibration and quality assurance) to ascertain the radiation dose absorbed by personnel.

Dosimerty Processor: Means an individual or organization that processes and evaluates individual monitoring equipment in order to determine the radiation dose delivered to the equipment. **10 CFR 20**

Effective Dose Equivalent (H_E): Is the sum of the products of the dose equivalent to the organ or tissue (H_T) and the weighting factor (W_T) applicable to each of the body organs or tissues that are irradiated ($H_E = \sum w_T H_T$). **10 CFR 20**

Elective Examination: An examination not requiring immediate execution and therefore able to be planned for the patient's convenience and safety.

Electromagnetic Radiation: See radiation.

Electron Volt: A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt. Large multiple units of the electron volt are frequently used. keV for thousand or kilo electron volts, MeV for million or mega electron volts.

Embryo/Fetus: Means the developing human organism from conception until the time of birth. **10 CFR 20**

Embryological Effects: Damage to an organism which occurs as a result of exposure of the organism to ionizing radiation during its embryonic stage of development.

Emulsion: The sensitive layer of photographic film containing tiny crystals of a silver compound embedded in a layer of gelatin.

Erg: The amount of work done by a force of one dyne acting through a distance of one centimeter (cm). Unit of energy and work which can exert a force of one dyne through a distance of one cm. It is equal to 10^{-7} joules (unit of work).

Exposure: Means being exposed to ionizing radiation or to radioactive material. **10 CFR 20**

> **Acute Exposure:** Radiation exposure of short duration.
>
> **Chronic Exposure:** Radiation exposure over a long duration by fractionation or protraction.
>
> **Medical Exposure:** Intentional physician prescribed exposure of an individual to radiation for diagnostic or therapeutic medical purposes.
>
> **Irradiation Time:** The time interval in a radiological examination within which X-rays are incident upon the body part under examination.

External Dose: Means that portion of the dose equivalent received from radiation sources outside the body. **10 CFR 20**

Extremity: Means hand, elbow, arm below the elbow, foot, knee, or leg below the knee. **10 CFR 20**

Eye Dose Equivalent: Applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 centimeters (300 mg/cm). **10 CFR 20**

Film Speed: A computed log relative exposure number needed to produce a density of 1.0 above gross fog - used for screen type, medical X-ray films.

Filter: Means material placed in the useful beam to absorb preferentially the less penetrating radiations. **30306(f)**

> **Added Filter:** Sheets of metal (usually aluminum or its equivalent) which are placed in the direct path of the X-ray beam.
>
> **Inherent Filter:** The X-ray tube and its housing such as the glass envelope (window) through which the X-ray beam passes.
>
> **Total Filtration:** The sum of the inherent and added filters.

Fixer: A chemical solution (acidic) which removes the unexposed and undeveloped silver halide crystals from the film so it will not discolor or darken with age or exposure to light. Fixer also hardens the gelatin containing the black metallic silver so film may be dried and resist damage from abrasions.

Fixer Retention: The inadequate removal of fixer from the film by the water in the wash tank of the processor. Retained fixer causes eventual brown discoloration of the radiograph.

Fluorography: The production of a photographic record of the image formed on the output phosphor of an image intensifier by the action of X-rays transmitted through the patient.

Fluoroscopy: A radiological examination utilizing fluorescence for observation of the transient image.

Focal Spot: A small area on the target of the anode toward which the electrons from the focusing cup of the cathode are directed. X-radiation originates at the focal spot.

> **Effective Focal Spot:** The apparent size of the radiation source when viewed from the central axis of the useful radiation beam.

Fog or Fogging: A cloudy appearance of the finished radiograph caused by several factors such as old or contaminated processing solutions, exposure to chemical fumes, faulty darkroom safelight, or scatter radiation.

> **Gross Fog:** Base density plus emulsion fog on an X-ray film.

Geiger-Mueller (GM) Counter: Highly sensitive, gas-filled radiation detection device.

Generator, X-ray: See X-ray generator.

Genes: Parts of chromosomes which determine the inherited traits of the offspring. Genes are contained in the nuclei of cells.

Genetic Effects: Mutations or other changes which are produced by irradiation of the genes in a cell which might reproduce.

Geometric Unsharpness: Unsharpness of the recording image due to the combined optical effect of finite size of the radiation source and geometric separation of the anatomic area of interest from the image receptor and the collimator.

Gonad Dose: See dose.

Gonad Shielding: Devices used during radiologic procedures to protect the reproductive organs from exposure to the useful X-ray beam. (A radiologist shall establish a list of all diagnostic X-ray examinations for which testicular/ovarian shielding shall be routinely used.)

Gradient: The measure of the slope of a line tangent to a characteristic curve.

> **Average Gradient:** Average of all gamma measurements in the diagnostic density range for X-ray films.

Gram: A metric unit of mass and weight nearly equal to one cubic centimeter of water at its maximum density.

Gray: (Gy) is the SI unit of absorbed dose. One gray is equal to an absorbed dose of 1 joule/kilogram (100 rads). **10 CFR 20**

Grid: A series of lead strips separated by spacers transparent to X-rays. A grid's function is to remove scattered radiation from the radiographic field which would impair the clarity of the image on the X-ray film. A grid's structure is characterized by many relationships, the most important being the grid ratio. Generally, the higher the grid ratio the better the scatter cleanup, but also the higher the patient radiation dose.

> **Bucky (Potter-Bucky Diaphragm):** A grid which moves during an exposure in order to eliminate grid lines (blur) from the image.

> **Stationary Grid:** A grid which does not move during the exposure.

Grid Ratio: A grid ratio is defined as the ratio between the height of the lead strips and the interspace distance between them. Thus, grid ratios denote the ratio of depth of lead strips to the width between the strips. The higher the grid ratio the higher the patient exposure.

Grid Pattern: Grid pattern refers to the orientation of the lead strips in their longitudinal axis.

Linear Grid: Linear grid is a grid in which lead strips are parallel to each other in their longitudinal axis.

Focused Grid: Is a grid made up of lead strips that are angled slightly so that they focus at some distance.

Parallel grid: Is a grid in which the lead strips are parallel when viewed in cross section.

Half-Value Layer (HVL): The thickness of a specified substance/material usually aluminum (for X-ray beam quality) or lead (for shielding purposes) which, when introduced into the path of a given beam of radiation, reduces the exposure rate by one-half.

H & D curve: See characteristic curve.

Health Physicist: A professional who is specially trained in radiation and health physics and concerns himself/herself with problems of radiation protection.

Health Physics: The science of protecting human beings from injury by radiation, and promoting better health through beneficial applications of radiation. (Also called Radiological Health).

Heel Effect: The heel effect refers to the unequal intensity of the X-ray beam, the intensity being higher on the cathode side of the beam and less intense on the anode side of the beam. (Non-uniform intensity is observed because a small fraction of the X-ray beam emitted in a direction nearly parallel to the angled target surface must pass through more target material before escaping from the target than does the major portion of the beam which is emitted more perpendicularly. NOTE: In addition to the non-uniform intensity the angled target also procures non-uniform image resolution due to variations in apparent focal spot size as viewed from various positions on the film.)

High Radiation Area. Means an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.1 rem (1mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates. **10 CFR 20**

Human Use: Means the internal or external administration of radiation or radioactive materials to human beings. **30100 (f)**

ICRP: The acronym of the International Commission on Radiological Protection which was established in 1928 by the Second International Congress of Radiology. It prepares recommendations to deal with the basic principles of radiation protection.

Image Receptor: A system for deriving a diagnostically usable image from the X-rays transmitted by the patient. Examples: screen/film system; stimulable phosphor; solid state detector.

Indirect Effect: Destructive chemical changes in body molecules which result when a specific molecule such as DNA is acted upon by free radicals which were previously produced from the interaction of radiation with water molecules.

Individual Monitoring Device/Equipment): Means devices designed to be worn by a single individual for the assessment of dose equivalent such as film badges, thermoluminescent dosimeters and personal ("lapel") air sampling devices. **10 CFR 20**

Inherent Filtration: See filter.

Installation: Means the location where one or more reportable sources of radiation are possessed. **30100 (g)**

Integral Dose: A calculated dose for a portion of the body, determined by (1) the size of the field exposed, (2) the skin dose, and (3) the depth of tissue at which the dose falls to one-half the skin dose.

Intensifying Screens: Devices which increase the brightness of the image produced by the action of X-rays upon a phosphor.

Interlock: Means a device for precluding access to an area of radiation hazard either by preventing entry or by automatically removing the hazard. **30306 (g)**

Inverse Square Law: The intensity of the radiation is inversely proportional to the square of the distance from the source.

Ion: An atom of a positive or negative electric charge as a result of having lost or gained one or more electrons or a free electron or other subatomic charged particle. (An atom or molecule which has one or more of its surrounding electrons separated from it and therefore carries an electrical charge.)

Ion Pair: A positively charged atom or molecule (ion) and an electron formed by the action of radiation upon a neutral atom or molecule.

Ion/Ionization Chamber: An X-ray measuring device in which gas is ionized in proportion to the quantity of X-ray energy passing through (lost in) the chamber.

Ionization: The process whereby one or more electrons is removed from a neutral atom by the action of radiation (the conversion of atoms to ions).

Ionizing Radiation: See radiation.

Joule (J): The unit of work equal to one newton (N), expended along a distance of one meter (1J = 1N x 1m).

Kilo Electron Volt (keV): One thousand electron volts (1,000 eV).

Kilovolt: A unit of electrical potential difference equal to 1,000 volts.

Kilovolt Peak (kVp): A unit of maximum or crest value of electrical potential difference between the anode and cathode of an X-ray tube. The kilovolt peak (kVp) determines the maximum penetrating ability of X-rays and refers to the "quality" of X-rays.

Latitude: The property of an X-ray film to have a great number of units of density produced within certain log-relative exposure numbers; longer latitude films have lower contrasts.

Leakage Radiation: Means all radiation coming from within the tube housing except the useful beam. **30306 (h)**

Leukemia: A blood disease which is characterized by overproduction of white blood cells. It may result from overexposure of the bone marrow to radiation.

Linear Hypothesis: The assumption that a dose-effect curve derived from data in the high dose-rate ranges may be extrapolated through the low dose range to zero. This implies that any amount of radiation can cause some damage.

Limits: (Dose limits) means the permissible upper bounds of radiation doses. **10 CFR 20**

Magnification: The ratio of image size to object size. The image may be larger than, smaller than, or equal in size to the object; so magnification can be greater than, equal to, or less than 1.

Member of the Public: Means an individual in a controlled or unrestricted area. However, an individual is not a member of the public during any period in which the individual receives an occupational dose. **10 CFR 20**

Milliampere (mA): The current (measured in milliamperes) flowing across the X-ray tube from the cathode to the anode. Milliampere (mA) multiplied by the time during which the beam strikes an object (measured in seconds) is milliampere-seconds (mAs) and is a measure of the "quantity" of X-rays.

Millirad (mrad): A division of the rad, equal to one one-thousandth of a rad (See rad).

Millirem (mrem): A division of the rem, equal to one one-thousandth of a rem (See rem).

Minor: Means an individual less than 18 years of age. **10 CFR 20**

Monitoring (Radiation Monitoring, Radiation Protection Monitoring): Means the measurement of radiation levels, concentrations, surface area concentrations or quantities of radioactive material and the use of the results of these measurements to evaluate potential exposures and doses. **10 CFR 20**

Mutation: A transformation of the gene which may be induced by radiation and may alter characteristics of the offspring.

NCRP: The acronym of the National Council on Radiation Protection and Measurements which is a nonprofit corporation chartered by Congress in 1964. The concern of NCRP is with the scientific and technical aspects of radiation protection.

Newton: The unit of force, which when applied to a one kilogram mass will give an acceleration of one meter per second per second.

Nonstochastic Effect: Means health effects, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a nonstochastic effect (also called a deterministic effect.) **10 CFR 20**

Occupational Dose: Means the dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation whether in the possession of the licensee or other person. Occupational dose does not include dose received from background radiation, as patient from medial practices, from voluntary participation in medical research programs, or as a member of the general public. **10 CFR 20**

Ohm: The practical meter-kilogram-second unit of electrical resistance equal to the resistance of a circuit in which a potential difference of one volt produces a current of one ampere.

Operator: Any individual who personally utilizes or manipulates a source of radiation.

Operator's Station: The area where the control panel for the operation of an X-ray machine is located. The operator's station at the control shall be behind a protective barrier either in a separate room, in a protective booth, or behind a shield which will intercept the useful beam and any radiation which has been scattered only once.

Other Official Agency Specifically Designated by the Department: Means an agency which the Department has entered into an agreement pursuant to section 114990 (old section 25810) of the Health and Safety Code. **30100 (j)**

Panel: The tabletop of the imaging unit as a whole.

Person: Means any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, agency, political subdivision of this State, any other state or political subdivision or agency thereof, and any legal successor, representative, agent, or agency of the foregoing, other than the United States Nuclear Regulatory Commission, the United States Department of Energy, or any successor thereto, and other than Federal Government agencies licensed by the United States Nuclear Regulatory Commission, under prime contract to the United States Department of Energy, or any successor thereto. **30100 (k)**

Personnel Dosimeters: See dosimeters.

Personnel Monitor. An appropriately sensitive device used to estimate the absorbed dose received by an individual.

Personnel Monitoring Equipment: Means devices designed to be worn or carried by an individual for the purpose of measuring the dose received by that individual (e.g., film badges, pocket chambers, pocket dosimeters, film rings, etc). **30100 (l)**

Phantom: An object used to simulate the absorption and scatter characteristics of the patient's body for radiation measurement purposes.

Photoelectric Absorption: An interaction between an X-ray photon and an orbital electron in which the photon surrenders all of its kinetic energy to the electron and ceases to exist. The atom responds by ejecting the electron from the shell. Photoelectric absorption is the process most responsible for the dose of radiation the patient receives during a radiographic procedure.

Photometry: The science of the measurement and study of the quantity and intensity of radiation visible to the human eye.

Photomultiplier Tube: A type of vacuum tube used to achieve electron gains. For example, one incident electron will create two secondary electrons which may in turn be used to create four secondary electrons, etc.

Photon: A quantity of energy emitted in the form of electromagnetic radiation. X-rays are examples of photons.

Phototimer: A device which automatically terminates an exposure when the required film density has been achieved. It accomplishes this by measuring the amount of radiation which has reached the film.

Pixel: A two-dimensional picture element in the presented image.

Pocket Ion Chamber: A small, pocket-sized ionization chamber used for monitoring radiation exposure of personnel. Before use it is given a charge and the amount of discharge during the period of use is a measure of the total radiation exposure during the period.

Possess: Means to receive, possess, use, transfer or dispose of radioactive material pursuant to this regulation. **30100 (m)**

Possessing a Reportable Source of Radiation: Means having physical possession of, or otherwise having control of, a reportable source of radiation in the State of California. **30100 (n)**

Protective Barrier: Means a barrier of attenuating materials used to reduce radiation exposure. **30306 (i)**

Primary Protective Barrier: Means a barrier sufficient to attenuate the useful beam to the required degree. **30306 (j)**

Protective Apron: An apron made of radiation absorbing materials, used to reduce radiation exposure.

Protective Glove: A glove made of radiation absorbing materials used to reduce radiation exposure.

Quality: A term used to describe the penetrating power of X-rays and is related to the energies of the photons in the useful or primary X-ray beam.

Quality Assurance (QA): Quality Assurance (QA) is a management tool that includes policies and procedures designed to optimize the performance of facility personnel and equipment. QA includes all of the following:

- o Quality control (QC)
- o Administration
- o Education of personnel
- o Preventive maintenance methods

Quality Control (QC): Quality Control (QC) refers to routine performance and interpretation of test equipment function and to corrective action needed and taken.

Quality Factor (Q): Means the modifying factor (listed in tables 1004(b).1 and 1004(b).2 of Section 20.1004) that is used to derive dose equivalent from absorbed dose. **10 CFR 20**

Quantity: A term used to describe the number of photons in an X-ray beam.

Quantum Mottle/Noise: Statistical fluctuations in the radiographic image which result in a grainy appearance. Mottle is more visible in a high-resolution, high-contrast image.

Rad: Is a special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joule/kilogram (0.01 gray). **10 CFR 20**

Radiation (Ionizing Radiation): Means gamma rays and X-rays, alpha and beta particles, high speed electrons, neutrons, protons, and other nuclear particles; but not sound or radio waves, or visible, infrared, or ultraviolet light. **30100 (o)**

Background Radiation: A term used to describe the radiation present in the natural environment. It is produced by radioactive substances in the earth's crust, in water, in air, and by cosmic rays from outer space.

Electromagnetic Radiation: A traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiations range from X-rays of short wavelength, through ultraviolet, visible and infrared regions, to radar and radio waves of relatively long wavelength.

Ionizing Radiation: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

Non-Ionizing Radiation: Electromagnetic or other radiation of insufficient energy to cause ionization or excitation of atoms with which it interacts (e.g., sound, microwaves).

Radiation Area: Means an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.05 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates. **10 CFR 20**

Radiation Machine: Means any device capable of producing radiation when the associated control devices are operated, but excluding devices which produce radiation only by the use of radioactive material. For fee purposes, when a radiation machine is equipped with two or more tubes that can be used separately, each tube shall be considered as a single machine, except for machines used solely for research and teaching. **30100 (p)**

Radiation Safety Officer: The person responsible for the radiation protection program at a licensed facility.

Radiobiology: That branch of biology which deals with the effects of radiation on biological systems.

Radiograph: A film or other recording produced by the action of X-rays transmitted through the patient.

Radiography: Utilizing ionizing radiation, this technique involves making shadow images on photographic emulsions. The image is the result of differences in attenuation of the radiation as it passes through the object in its path. (The production of images on film by the action of X-rays transmitted through the patient.)

Radiopaque Medium: A material which absorbs X-rays and hence casts a shadow on the X-ray film or fluoroscopic screen.

Radiosensitivity: The susceptibility of cells, tissues, organ systems, organisms, or any living substance to the injurious action of radiation.

Real Image: An image created by the actual intersection of light rays and defined as being one which can be displayed on a diffusing screen.

Reference Man: Means a hypothetical aggregation of human physical and physiological characteristics arrived at by international consensus. These characteristics may be used by researchers and public health workers to standardize the results of experiments and to relate biological insult to a common base. **10 CFR 20**

Registrant: Means any person who is registering or who has registered with the Department pursuant to Group 1.5, Registration of Sources of Radiation. **30100 (r)**

Rem: Is the special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor (1rem = 0.01 sievert). **10 CFR 20**

Remnant Radiation: That part of the X-ray beam which has passed through the patient and reaches the film. It consists of non-interacting and small-angle scattered photons.

Repeats/Retakes: Additional radiographs taken because of technical or mechanical error leading to increased radiation dose for the patient and the radiation worker.

Reportable Sources of Radiation: Means (either of the following): (1) Radiation machines, when installed in such manner as to be capable of producing radiation. **30100 (s)**

Resolution: The process or capability of distinguishing closely adjacent optical images. (In the context of an image system, the output of which is finally viewed by the eye, it refers to the smallest size of highest spatial frequency of an object of given contrast that is just perceptible. The intrinsic resolution, or resolving power, of an imaging system is measured in line pairs per millimeter (lp/mm), ordinarily using a resolving power target. The resolution actually achieved when imaging lower contrast objects is normally much less, and depends upon many variables such as subject contrast levels and noise of the overall imaging system.)

Resolving Power: This term refers to the ability to distinguish separate images of line pairs (lines and spaces) per millimeter.

Restricted Area: Means an area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. **10 CFR 20**

Scattered Radiation: Means radiation that, during passage through matter, has been deviated in direction. **30306 (k)**

Secondary or Stray Radiation: Means radiation not serving any useful purpose. It includes leakage and scattered radiation.

Secondary Protective Barrier: Means a barrier sufficient to attenuate stray radiation to the required degree. **30306 (l)**

Sensitometer: An instrument used to expose film to precisely controlled steps of increasing light intensity. (An instrument that produces a series of controlled exposures on a sheet of photographic material.)

Sensitometric Curve: The visual line graph produced by plotting density-exposure relationships for photographic films. Also referred to as a characteristic curve or an H & D curves.

Sensitometry: The act, the art, or the science of measuring sensitivity, as of photographic material.

Serial Radiography: A radiographic procedure in which a sequence of radiographs is made rapidly by using an automatic cassette changer, image intensifier/TV chain, etc.

Shallow-Dose Equivalent (H_S): Applies to the external exposure of the skin and an extremity, and is taken as the dose equivalent at a tissue depth of 0.007 centimeter (7 mg/cm^2) averaged over an area of 1 square centimeter. **10 CFR 20**

Shield/Shielding: Material which is interposed between a radiation source and an irradiated site for the purpose of minimizing the radiation hazard (used to prevent or reduce the passage of radiation). Shielding is usually made of lead which is dense and absorbs radiation easily. Shielding is often used to protect the reproductive organs, testes or ovaries, from the X-ray beam during an examination.

Shoulder of Curve: The portion above the straight line of the sensitometric curve.

Shutter: Means a device, generally of lead, fixed to an X-ray tube housing to intercept the useful beam. **30306 (m)**

Sievert: Is the SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the quality factor (1 Sv = 100 rems). **10 CFR 20**

Somatic: Pertaining to the body tissue other than reproductive cells.

Source-to-Image Distance (SID): The distance measured along the central ray from the center of the front of the surface of the source (X-ray focal spot or sealed radioactive source) to the surface of the image detector.

Source of Radiation: Means a discrete or separate quantity of radioactive material or a single radiation machine. **30100 (v)**

Source-Surface Distance /Source-Skin Distance (SSD): The distance measured along the central ray from the center of the front surface of the source (X-ray focal spot) to the surface of the irradiated object or patient.

Speed Factor: With intensifying screens, the speed factor is defined as the ratio of the exposure required without screens to the exposure required with screens to get the same degree of blackening of X-ray films.

Spot Film: A radiograph taken during a fluoroscopic examination for the purpose of providing a permanent record of an area of interest or to verify the filling of a void with contrast media.

Step Wedge (Penetrometer): A device made up of different density filters shaped in a step-like form. (A device made up of different density filters shaped in a step-like form where each step or filter differs in density by the square root of 2.)

Sterility: Inability (either temporary or permanent) to reproduce.

Stochastic Effects: Means health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects. **10 CFR 20**

Straight Line Portion of a Sensitometric Curve: On medical, screen-type X-ray film, the part of the curve from a density of 0.25 to a density of 2.0 above the gross fog.

Stray Radiation: Means radiation not serving any useful purpose. It includes leakage and scattered radiation. **30306 (n)**

Supervision: According to section 114850 (g) [old section 25661 (h)] of the Health and Safety Code, supervision means responsibility for, and control of, quality, radiation safety, and technical aspects of all X-ray examinations and procedures.

Survey: Means an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, or presence of radioactive material or other sources of radiation. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present. **10 CFR 20**

Target: Material at which electrons from the cathode in an X-ray tube are aimed in order to produce X-rays. (The part of an X-ray tube anode assembly impacted by the electron beam to produce the useful X-ray beam.) See anode.

Target-Film Distance (TFD): The distance from the X-ray tube target (anode) to the X-ray film measured either in inches or centimeters.

Target-Skin Distance (TSD): The distance from the X-ray tube target (anode) to the skin of the patient where the X-ray beam enters the body.

Tenth Value Layer (TVL): Thickness of a specified substance which, when introduced into the path of a given beam of radiation, reduces the kerma rate to one-tenth of its original rate.

Thermoluminescence: The property of certain inorganic crystals to emit light when heated following exposure to ionizing radiation. The quantity of light is related to the total absorbed dose.

Thermoluminescent Dosimetry (TLD): A dose measurement system utilizing certain inorganic crystals, such as lithium fluoride (LiF). Energy is accumulated by radiation induced dislocation of electrons. Upon heating the TLD material, the dislocated electrons return to their original locations releasing the stored energy in the form of light. The quantity of emitted light is proportional to the absorbed radiation.

Therapeutic-Type Tube Housing: Means, (1) For X-ray therapy equipment not capable of operating at 500 kVp or above, an X-ray tube housing so constructed that the leakage radiation at a distance of 1 meter from the source does not exceed 1 rad in an hour when the tube is operated at its maximum rated continuous current for the maximum rated tube potential. (2) For X-ray therapy equipment capable of operating at 500 kVp or above, an X-ray tube housing so constructed that the leakage radiation at a distance of 1 meter from the source does not exceed either 1 rad in an hour or 0.1 percent of the useful beam dose rate at 1 meter from the source, whichever is greater, when the machine is operated at its maximum rated continuous current for the maximum rated accelerating potential. (3) In either case, small areas of reduced protection are acceptable provided the average reading over any 100 square centimeters area at 1 meter distance from the source does not exceed the values given above. **30306 (o)**

This Regulation: Means California Administrative Code, Title 17, Chapter 5, Subchapter 4. **30100 (y)**

Toe of the Sensitometric Curve: Portion below the straight line of the sensitometric curve.

Tomography: A special technique to show in detail images of structures lying in a predetermined place of tissue, while blurring or eliminating detail in images of structures in other planes.

Tomography, Computed (CT): The method of imaging which utilizes narrow X-ray beam images taken over a 360 degree projection of an object. These images are not recorded like any other radiographic or fluoroscopic images, instead, the X-ray beam detectors feed the images directly into the computer. The computer reconstructs the X-ray beam images to produce transaxial images of the object.

Useful Beam: Means that part of the radiation which passes through the window, aperture, cone, or other collimating device of the tube housing. **30306 (p)**

Use: Means any person who is licensed to possess radioactive material or who has registered as possessing a reportable source of radiation pursuant to Groups 1.5 and 2 of this subchapter, or who otherwise possesses a source of radiation which is subject to such licensure or registration. **30100 (z)**

Unrestricted Area: Means an area, access to which is neither limited nor controlled by the licensee. **10 CFR 20**

Very High Radiation Area: Means an area, accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 grays) in 1 hour at 1 meter from a radiation source or from any surface that the radiation penetrates. **10 CFR 20**

Virtual Image: A type of image usually found in visual optical instruments in which the light rays do not actually intersect, but only appear as if they had.

Visual Acuity: The ability of the eye to resolve the angular separation of two objects. For the human eye, it is usually between one and two minutes of arc.

Voxel: A volume element in the object being imaged. The mean attenuation coefficient of the voxel determines the CT (Hounsfield) number of the pixel.

Week: Means 7 consecutive days starting on Sunday. **10 CFR 20**

Weighting Factor: For an organ or tissue (T) is the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly. For calculating the effective dose equivalent, the values of W are:

Organ Dose Weighting Factors

Organ or tissue	w_T
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30 [1/]
Whole Body	1.00 [2/]

1/ 0.30 results from 0.06 for each of 5 "remainder" organs (excluding the skin and the lens of the eye) that receive the highest doses.

2/ For the purpose of weighting the external whole body dose (for adding it to the internal dose a single weighting factor w = 1.0 has been specified). The use of other weighting factors for external exposure will be approved on a case-by-case basis until such time as specific guidance is issued.

Whole Body: Means for purposes of external exposure, head, trunk (including male gonads), arms above the elbow, or legs above the knees. **10 CFR 20**

X-Rays: Penetrating electromagnetic radiation whose wavelengths are shorter than those of visible light. For radiographic purposes, X-rays are usually produced by bombarding a metallic target with fast electrons in a vacuum.

X-ray Generator: A device which supplies electrical power to the X-ray tube. It does not, as the name implies, actually generate X-rays.

X-ray Personnel: The following individuals are legally allowed to use diagnostic X-rays on human beings:

- Doctors (MD's, DO's, DPM's, DC's) who hold X-ray Supervisor and Operator Radiography Permit or Radiologist Certificate issued by the Radiologic Health Branch.
- Radiologic technologists who hold Diagnostic Radiologic Technologist Certificate issued by the Radiologic Health Branch.
- Limited permit X-ray technicians who hold appropriate limited permits issued by the Radiologic Health Branch.
- On-the-job trainees who have been issued authorization by the Radiologic Health Branch to undergo OJT training.
- Students enrolled in a school of radiologic technology approved by the Radiologic Health Branch.

APPENDIX NO. 20

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